IDENTIFICATION OF THE INSTREAM FLOW REQUIREMENTS FOR ANADROMOUS FISH IN THE STREAMS WITHIN THE CENTRAL VALLEY OF CALIFORNIA

Annual Progress Report
Fiscal Year 1995

U.S. Fish and Wildlife Service
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Prepared by staff of
The Instream Flow Assessments Branch

PREFACE

The following is the first annual progress report prepared as part of the Anadromous Doubling Plan Instream Flow Investigations, a 5-year effort which began in February, 1995. Title 34, Section 3406(b)(1)(B) of the Central Valley Project Improvement Act, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service (FWS) after consultation with the California Department of Fish and Game (CDFG). The purpose of this investigation is to provide reliable scientific information to the U.S. Fish and Wildlife Service Central Valley Anadromous Fish Restoration Program to be used to develop such recommendations for Central Valley rivers.

To those who are interested, comments and information regarding this program and the habitat resources of Central Valley rivers are welcomed. Written comments or information can be submitted to:

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late-fall, winter and spring), steelhead trout, and white and green sturgeon. In December 1994, the FWS, Ecological Services, Instream Flow Assessments Branch prepared a study proposal to use the Service's Instream Flow Incremental Methodology (IFIM) to identify the instream flow requirements for anadromous fish in selected streams within the Central Valley of California. These streams included the Sacramento, Lower American, Merced, and Bear Rivers, and Butte Creek. During subsequent meetings in January with William Snider of CDFG and representatives of the FWS Central Valley Anadromous Fish Restoration Program this list was revised to exclude the Bear River and Butte Creek. Considering available manpower and funding, these streams were considered to be of lower priority than the Sacramento, Lower American, and Merced Rivers. Other factors in this decision were the availability of existing information on the Bear River and a pending proposal for the possible removal of some of the diversion dams on Butte Creek. The studies on the selected rivers will be closely coordinated with study efforts proposed by CDFG.

The Sacramento River study is a five-year effort to be concluded in fiscal year 1999. Specific goals of the study are to determine the relationship between streamflow and physical habitat availability for all life stages of chinook salmon (fall, late-fall, winter, and spring runs) and steelhead trout; and to identify flows at which redd dewatering and juvenile stranding conditions occur. The instream flow requirements for white and green sturgeon may also be studied, however, the inclusion of these species requires further scoping. The study components include: 1) compilation and review of existing information; 2) consultation with other agencies and biologists; 3) field reconnaissance; 4) development of habitat suitability criteria (HSC); 5) study site selection and transect placement; 6) hydraulic data collection; 7) construction and calibration of reliable hydraulic simulation models; 8) construction of habitat models to predict physical habitat availability over a range of river discharges; and 9) preparation of draft and final reports. The FY95 Scope of Work (SOW) submitted in February identified study tasks to be undertaken. These included project scoping (study components 1 and 2), field reconnaissance (study component 3), and beginning the development of HSC (study component 4).

The Lower American River study is a one-year effort to be concluded in fiscal year 1995 as indicated in the SOW. The purpose of this study is to produce a habitat model predicting physical habitat availability for spawning fall-run chinook salmon and steelhead trout. This information will supplement data which has been collected by CDFG for several years to produce comprehensive instream flow recommendations. Habitat model results will be submitted to them for enclosure in their final report on the Lower American River. The study components include: 1) Field reconnaissance and selection of study sites; 2) placement of transects in selected study sites; 3) hydraulic data collection; 4) construction and calibration of reliable hydraulic simulation models; 5) construction of habitat models to predict spawning habitat availability over a range of river discharges; and 6) preparation and submittal of a report detailing study procedures and model results.

The Merced River study is a 1.5 year effort to begin in October 1996. The purpose of this study is the same as that for the Lower American River study described above- to produce a habitat model predicting physical habitat availability for spawning fall-run chinook salmon and steelhead trout. This information will supplement data which has been collected by CDFG for several years to produce comprehensive instream flow recommendations. Habitat model results will be submitted to them for enclosure in their final report on the Merced River. The study components include: 1) Field reconnaissance and selection of study sites; 2) placement of transects in selected study sites; 3) hydraulic data collection; 4) construction and calibration of reliable hydraulic simulation models; 5) construction of habitat models to predict spawning habitat availability over a range of river discharges; and 6) preparation and submittal of report detailing study procedures and model results. No study tasks were undertaken in fiscal year 1995 on the Merced River.

The following sections summarize project activities between February and September 1995. The FY96 SOW submitted 6 October, 1995 describes study tasks to be undertaken in fiscal year 1996 and study products to be submitted.

SACRAMENTO RIVER
SCOPING AND FIELD RECONNAISSANCE

Methods

The first step in our scoping process was to review existing information. Based on this information, we prepared three scoping reports (Available Information, Hydrology, and Chinook Salmon HSI Curves). The Available Information report primarily summarizes information on run sizes, spatial and temporal distribution, and other biological requirements of different life stages of steelhead trout, white and green sturgeon, and the four races of chinook salmon. The Hydrology report synthesizes historic Sacramento River flows. The Chinook Salmon HSI Curves (habitat suitability criteria) report analyzes the use of different HSI curves with an existing Sacramento River PHABSIM hydraulic data deck (PHABSIM is the Physical Habitat Simulation component of the IFIM. The data deck referred to was obtained from the CDWR and was used in their 1993 study). We also analyzed the latest six years of aerial redd survey data collected by Frank Fisher (CDFG) for each of the four runs of chinook salmon to determine the most heavily used spawning mesohabitat units (primarily riffles).

In determining the scope of the Sacramento Instream Flow Investigation, we consulted with members of the CVPIA Anadromous Doubling Program Mainstem Sacramento River Technical

Team (Rich Johnson, NCVFRO; Harry Rectenwald, CDFG Region 1; Ralph Hinton, CDWR), members of the CVPIA Anadromous Doubling Program Sturgeon Technical Team (Kurt Brown, NCVFRO and Dave Kohlhorst, CDFG Bay Delta Division), Frank Fisher (CDFG Inland Fisheries Division), and CDWR and CDFG staff who worked on the CDWR Sacramento River Instream Flow Study or other related studies (Charlie Brown, Bill Mendenhall, Shawn Pike, Curtis Anderson, Stacy Cepello and Koll Buer).

Results

The three scoping reports, summarizing the results of most of our scoping activities during fiscal year 1995, are included as Appendices A through C to this report. The existing information that we reviewed is listed in Appendix D. Results of the analysis of aerial redd data will be presented in the FY96 annual report. Field reconnaissance was not begun in fiscal year 1995 because of high Sacramento River flows and staff time required to finish work on the Trinity River Flow Evaluation.

SACRAMENTO RIVER
HABITAT SUITABILITY CRITERIA (HSC) DEVELOPMENT

Methods

Little was accomplished with respect to development of HSC for the salmonid species as the project was not fully implemented until February when scoping activities began. Through analysis of aerial red survey data and discussions with the parties mentioned above, we did identify the areas where substantial spawning activity for each race has been observed in recent years. Our criteria development efforts will likely concentrate in these areas for the duration of the study. We also began to consider the sampling techniques which will be needed to adequately sample deeper water (> 2m) spawning habitats. Deeper water is frequently used by Sacramento River chinook salmon, particularly winter-run, for spawning. In July, a series of dives was conducted with staff from the NCVFRO to determine if techniques they use to map substrate composition could also be used to identify redds and measure hydraulic conditions adjacent to them. The technique employs SCUBA divers pulled behind a jet-powered boat while grasping plexiglass planing boards which enable the divers to maneuver just above the river bottom. The divers are in constant radio contact with the boat and with each other at all times. When commanded, the boat can cease forward movement and remain stationary in the current allowing the divers to closely examine the area around them.

Staff started developing spawning criteria for white sturgeon in the Sacramento River using a Delphi Analysis. A Delphi Analysis is a technique used to develop HSC from information other than direct field observations (Category I criteria). The most common Delphi exercise uses a questionaire designed by a small monitor team and sent to a larger respondent group. Members of the Delphi Analysis panel were selected based on their experience with collecting data, primarily using spawning mats, for white sturgeon spawning criteria. Members of the Delphi Analysis panel are Mike Parsley (Columbia River Research Laboratory, NBS), Ray Schaffter (CDFG Stockton), George McCabe (NMFS), Jim Chandler (Idaho Power Company), Paul Anders (Kootenai Tribe of Idaho), Larry Hildebrand (RL&L Environmental Services LTD) and Vaughn Paragamian (Idaho Department of Fish and Game). The first round of the Delphi Analysis presented criteria developed for the Lower Columbia River and limited spawning mat data collected in the Sacramento River by Ray Schaffter. In the first round, members of the Delphi panel were asked to identify water column depths and average water column velocities which would be the lowest and highest considered optimal, and which would have Suitability Index values of zero and 0.5. In addition, the panel was asked to estimate Suitability Index values for the following substrate types: plant detritus, compacted clay, silt/fine clay, sand, gravel, cobble, boulder and bedrock. In subsequent rounds, the median and first and third quartile values of the panel's responses were presented to the panel, and members were given the opportunity to revise their answers, including explaining the basis for their responses.

Results

The identification and marking of deep water redds should be possible using the methodology described above. Assuming field testing of the method confirms this, it will be a breakthrough in identifying suitable deep water spawning conditions. We intend to use this sampling technique in fiscal year 1996 and will report on the results of these efforts next year.

The first two rounds of the Delphi Analysis were completed by the end of September 1995. Final results of the Delphi Analysis will be presented in the FY96 annual report.

LOWER AMERICAN RIVER

Methods

Staff met in February with representatives from CDFG to review aerial redd survey photographs, redd count data, and habitat maps which they had collected over the last four years. From this information nine potential study sites were selected for collection of hydraulic data to construct the necessary hydraulic models. Shortly thereafter the river was reconnoitered at a streamflow of approximately 5000 cfs to assess study logistics (i.e, access points, property ownership, recreational use, study site boundaries, possible surveying complications). In March, two transects were placed at each site to represent the hydraulic conditions present. These transects were established above the 6,000 cfs waters edge on each side of the river using 9mm diameter rebar driven into the ground or lag bolts placed in tree trunks. Permanent benchmarks, one primary and one secondary, were also established at each site to be used as reference elevations during the course of the study. Hydraulic data collection on established transects was begun in early April. The final report for the study will contain a detailed description of the methods and procedures followed.

Results

The FY95 SOW indicated that the American River study would be completed and a final report submitted at the end of the fiscal year. Unfortunately, the project was not able to proceed as planned. The extremely wet winter necessitated high dam releases (>5,000 cfs) through mid-July and on 17 July the failure of Folsom Dam spillway gate #3 released over 45,000 cfs into the Lower American for over a week. After this improbable event, our flexibility in arranging releases needed for data collection was greatly reduced and we had to work with whatever the Bureau had to release to meet their various needs. For our modelling purposes, we had hoped to collect data at approximately 5000 and 1500 cfs with additional measurements taken at two streamflows evenly spaced between; and we had hoped to do so by 1 August. This would have enabled us to complete the study as scheduled. Working on short notice with respect to scheduled releases, we were finally able to collect the necessary data but did not complete the task until 10 October. In order to take advantage of the opportunity to begin fall-run HSC development on the Sacramento River and habitat map the river while present flow levels persist, we will submit the final report for the Lower American River by the end of the second quarter of fiscal year 1996 as indicated in the FY96 SOW.

APPENDIX A

Available Information

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Upper Sacramento River IFIM Study Scoping Report

AVAILABLE INFORMATION

Prepared By
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May 1995

Hydrology

The portion of the Sacramento River accessible to anadromous fish is from Chipps Island (River Mile 0) to Keswick Dam (River Mile 302). Flows in this portion of the Sacramento River are heavily influenced by two Central Valley Project (CVP) features: storage in Shasta Reservoir and diversions from the Trinity River basin via Whiskeytown Reservoir to Keswick Reservoir. Overall, the main effects of the CVP on Sacramento River flows is a modest decrease in February through April flows and a substantial increase in June through October flows (Figure 1); however, the CVP has likely produced a much greater decrease in Sacramento River flows during the non-irrigation season (October through March) in dry years, since minimum required releases from Keswick (3,250 cfs) are less than 200,000 acre-feet/month.

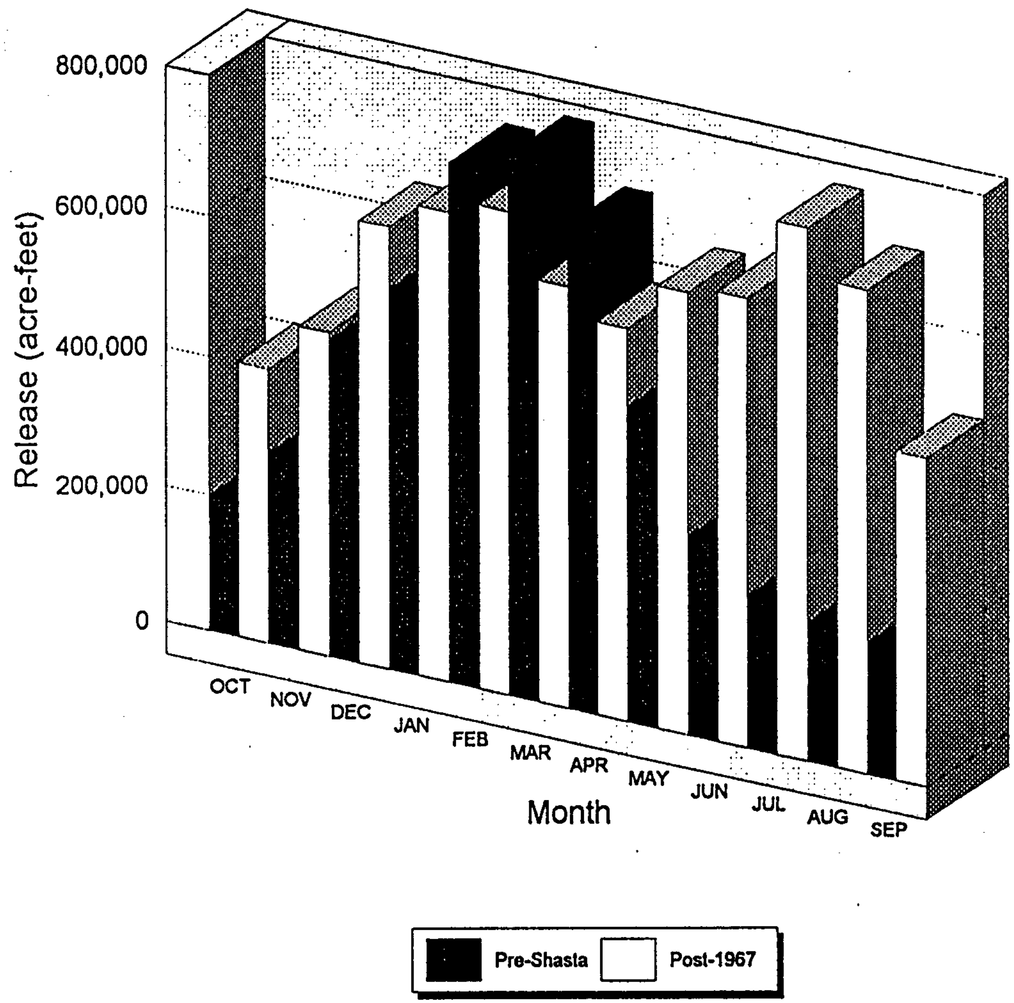
Red Bluff Diversion Dam (RBDD), at River Mile 243, and Anderson-Cottonwood Irrigation District (ACID) Dam, at River Mile 298.5, are partial barriers to anadromous fish. Migrating sturgeon were excluded from the Sacramento River between Keswick Dam and RBDD from 1966 to 1986, since they have never been observed passing through the RBDD fish ladders. To improve fish passage conditions at RBDD, especially for winter-run salmon, gates were raised during the non-irrigation seasons beginning in 1986-87 and 1987-88. Although salmon were completely blocked from migrating past RBDD during part of the drawdown process, salmon passage issues of delay and blockage were dramatically improved when the gates were raised, with no blockage and an average delay time of only 3 hours, versus around 40% blockage and up to several weeks delay with the gates in. The RBDD gates are currently raised 8 months of the year, from September 15 to May 15. When the RBDD gates are lowered, approximately 6 miles of the Sacramento River above RBDD are inundated under Lake Red Bluff. No salmon spawning has been observed in Lake Red Bluff when the RBDD gates are lowered, but there was considerable fall-run spawning in this portion of the Sacramento River in 1994 after the RBDD gates were raised. The flashboards for the ACID dam are typically in place from early April through late October or early November. Fluctuations in Sacramento River flow required to install, remove or adjust the flashboards results in stranding of juvenile salmonids and dewatering of redds. In addition, there are adult fish passage problems at the ACID dam when the flashboards are installed due to inadequate fish ladders. Sacramento River tributaries, major diversions and gages are given in Table 1.

Anadromous Fishery Resources

Native anadromous fish species in the upper Sacramento River include all four runs (fall, late-fall, winter and spring) of chinook salmon, steelhead trout, white sturgeon, green sturgeon, and Pacific lamprey. Individuals of four other salmon species, coho, chum, sockeye and pink, are rare in the Sacramento River system (Hallock and Fry 1967). The Sacramento River winter-run race of chinook salmon was classified as endangered by NMFS on February 4, 1994, pursuant to the Endangered Species Act (National Marine Fisheries Service 1994). Areas designated as critical habitat for winter-run chinook salmon include: "the Sacramento River from Keswick Dam, Shasta County (river mile 302) to Chipps Island (river mile 0) at

FIGURE I Sacramento River

Average Monthly Release at Keswick Dam



Source - Preliminary Administrative Draft, Surface Water Existing Conditions Technical Appendix prepared on the implementation of the CVPIA.
Post-1967 flows include Trinity River flows added at Keswick

Table 1
Sacramento River Gages, Tributaries and Major Diversions

	River mile	Description
Keswick Gage	*301.4*	
Middle Cr	*301*	*Westside Trib*
Salt Cr	*300.8*	*Westside Trib*
ACID	*298.5*	*Diversion*
Sulfur Cr	*297*	*Eastside Trib*
Olney Cr	*289.5*	*Westside Trib*
Clear Cr	*289.3*	*Westside Trib*
Churn Cr	*284.7*	*Eastside Trib*
Clover Cr	*284.2*	*Eastside Trib*
Stillwater Cr	*281*	*Eastside Trib*
Cow Cr	*280.2*	*Eastside Trib*
Bear Cr	*277.6*	*Eastside Trib*
Ash Cr	*277.2*	*Eastside Trib*
Anderson Cr	*273.8*	*Westside Trib*
Cottonwood Cr	*273.3*	*Westside Trib*
Battle Cr	*271.4*	*Eastside Trib*
Frazier Cr	*267.7*	*Westside Trib*
Inks Cr	*264.7*	*Eastside Trib*
Bend Br Gage	*260.3*	
Spring Cr	*257.7*	*Westside Trib*
Paynes Cr	*253*	*Eastside Trib*
Sevenmile Cr	*250.8*	*Eastside Trib*
Red Bluff Gage	*250.4*	
Blue Tent Cr	*247.6*	*Westside Trib*
Dibble Cr	*246.7*	*Westside Trib*
Reeds Cr	*244.8*	*Westside Trib*
Red Bank Cr	*243.1*	*Westside Trib*
RBDD	*243*	*Diversion*
Salt Cr	*240.2*	*Eastside Trib*
Craig Cr	*239.3*	*Eastside Trib*
Antelope Cr	*235*	*Eastside Trib*

Oat Cr	*233*	*Westside Trib*
Elder Cr	*230.4*	*Westside Trib*
Mill Cr	*230*	*Eastside Trib*
McClure Cr	*226.6*	*Westside Trib*
Thomes Cr	*226*	*Westside Trib*
Toomes Cr	*222.5*	*Eastside Trib*
Deer Cr	*219.6*	*Eastside Trib*
Woodson/Vina Gage	*218.3*	
Jewett Cr	*215.2*	*Westside Trib*
Burch Cr/Rice Cr	*209*	*Westside Trib*
GCID	*206.2*	*Diversion*
Hamilton City Gage	*199.3*	
Pine Cr	*196*	*Eastside Trib*
Big Chico Cr	*193*	*Eastside Trib*
Stony Cr	*190*	*Westside Trib*
Ord Ferry Gage	*184*	
Butte City Gage	*168.6*	

the *westward margin of the Sacramento-San Joaquin Delta, all waters from Chipps Island westward to Carquinez Bridge, including Honker Bay, Grizzly Bay, Suisun Bay, and Carquinez Strait, all waters of San Pablo Bay westward of the Carquinez Bridge, and all waters of San Francisco Bay (north of the San Francisco/Oakland Bay Bridge) from San Pablo Bay to the Golden Gate Bridge*" (National Marine Fisheries Service 1993). Sturgeon are common at least as far upstream as River Mile 243, since 28 adult white sturgeon and 19 adult green sturgeon were observed from 1989 through 1991 from River Mile 233 to 243 (Brown 1994); sturgeon have been observed by river guides as far upstream as River Mile 292 (Brown 1995). Two introduced anadromous fish species, American shad and striped bass, are common in the upper Sacramento River.

Anadromous Salmonids

Prior to the construction of Shasta and Keswick Dams, and other barriers to fish migration on tributaries of the Sacramento River, winter-run salmon (possibly more than 200,000) spawned during June and July in the upper reaches of the Little Sacramento, McCloud and lower Pit Rivers, tributaries of the Sacramento River upstream of Shasta Dam, while spring-run salmon spawned in the upper reaches of the Sacramento River and its tributaries. While winter-run were blocked from their historic spawning areas by the construction of Shasta and Keswick Dams in the early 1940's, winter-run were able to spawn in the Sacramento River downstream of Keswick dam as a result of cooler summer water temperatures resulting from CVP releases. In the 1960's, 98% of winter-run chinook salmon spawned in the upper Sacramento River (Hallock and Fry 1967), with most of the remainder spawning in Battle Creek (Figure 1), a tributary of the Sacramento River. Winter-run are believed to have been extirpated from Battle Creek; thus, virtually all winter-run now spawn in the upper Sacramento River. Most of the fall, late-fall and spring-run passing RBDD spawn in the mainstem Sacramento River. Of the fall-run salmon passing RBDD, around 7% spawn in Sacramento River tributaries, including Paynes, Battle, Cottonwood, Bear, Cow, and Clear Creeks, while around 10% are spawned at the Coleman National Fish Hatchery (NFH), located on Battle Creek, approximately 6 miles above the confluence of Battle Creek with the Sacramento River. Around 4% of late fall-run salmon passing RBDD spawn in Sacramento River tributaries, including Cottonwood, Cow and Clear Creeks, while around 3% are spawned at the Coleman NFH. Finally, around 8% of spring-run passing RBDD spawn in tributaries of the Sacramento River, including Battle, Cottonwood, South Cow and Clear Creeks.

Based on data from 1967 to 1974, 28% of the adult steelhead migrating past RBDD spawn in the upper reaches of Sacramento River tributaries, including Paynes, Battle, Cottonwood, and Cow Creeks, between RBDD and Keswick Dam, and 28% are spawned at the Coleman NFH, while the remainder are caught by sport fishermen; very few, if any, steelhead spawn in the mainstem Sacramento River (Leidy et al 1984). About 65% of the adult steelhead migrating past RBDD appear to be fish that were propagated at the Coleman NFH (Leidy et al 1984). In lower Central Valley rivers, steelhead tend to occur in tailwater populations below dams (Dennis McEwan, CDFG, personal communication); accordingly, steelhead might be expected to spawn just below Keswick Dam. No steelhead were observed spawning during CDFG's data collection for chinook salmon spawning habitat suitability curves (Charlie Brown, CDFG, personal communication). Possible steelhead redds have been observed during aerial redd surveys in three areas: downstream of Tobiasson Riffle (River Mile 291.5), at the Golfcourse Riffle (River Mile 292.5), and at Turtle Bay (River Mile 297) (Frank Fisher, CDFG, personal communication). These redds were too small to be chinook salmon redds, but could also have been resident rainbow trout ("river trout") or lamprey redds. Similar redds were observed during SCUBA surveys of redds at Turtle Bay (Scott Hamelberg, NCVFRO, personal communication). The redds were constructed in April or May, while steelhead in Sacramento River tributaries, such as Battle Creek, tend to spawn in late December through February, suggesting that these might be river trout redds, rather than steelhead redds. Identification of steelhead, versus river trout, would require examination of scales for ocean growth patterns (Dennis McEwan, CDFG, personal communication).

Based on catch data, the average run size for all chinook salmon runs combined on the Sacramento River was around 600,000 fish prior to 1915 (Leidy et al 1984). The estimated carrying capacity of the Sacramento River between RBDD and Keswick Dam is 400,000 fall-run, 150,000 late fall-run, 200,000 winter-run, and 150,000 spring-run, for a total of 900,000 chinook salmon for all runs combined (White 1991). Table 2 summarizes recent chinook salmon population estimates (data from Mills and Fisher 1994).

Table 2
Number of Chinook Salmon Spawning in the Upper Sacramento River

Year	Fall-run	Late fall-run	Winter-run	Spring-run
1967-91	76,701	14,159	23,109	11,089
1991	28,963	6,531	191	773

Table 3 summarizes the timing of upstream migration of salmonids, as derived from data from CDFG for adjusted fish ladder counts at RBDD. I determined whether the timing of steelhead and each salmon run was different for wet versus dry years using a Hotelling's T^2-test. Data were used from years where counts were made for all months in which steelhead or the salmon run passed (starting in 1967 or 1970 and ending in 1985 to 1988). Within that time period, I defined dry years as those years (1976, 1977, 1979, 1981, 1985, 1987, 1988) categorized as dry or critical under the D-1485 water year classification system, while all other years were

Table 3
Timing of Adult Salmonid Migration

				Winter run		Spring run	
Month	Steelhead	Fall run	Late fall run	Wet	Dry	Wet	Dry
Jan	6%		23%	7%	25%		
Feb	3%		17%	14%	19%		
Mar	3%		10%	27%	28%	1%	
Apr	1%		3%	28%	18%	10%	3%
May	2%			15%	6%	16%	12%
Jun	1%			6%	2%	16%	14%
Jul	1%	1%		2%	1%	17%	21%
Aug	4%	8%				21%	30%
Sep	23%	31%				18%	18%
Oct	36%	41%	6%			1%	2%
Nov	15%	16%	17%				
Dec	5%	3%	24%	2%	1%		

defined as wet years. There were significant differences between wet and dry years in the run timing of winter ($p = 0.005$, $N = 19$) and spring ($p = 0.050$, $N = 22$) run salmon. However, there were no significant differences between wet and dry years in the run timing of fall ($p = 0.42$, $N = 16$) or late fall ($p = 0.289$, $N = 19$) run salmon or of steelhead. Table 4 summarizes timing of chinook salmon spawning (U.S. Fish and Wildlife Service 1990).

Table 4
Timing of Adult Salmon Spawning

Month	Fall run	Late fall run	Winter run	Spring run
Jan		21%		
Feb		50%		
Mar		29%		
Apr				
May			24%	
Jun			61%	
Jul			13%	
Aug			2%	13%
Sep	2%			87%
Oct	28%			
Nov	60%			
Dec	10%			

Table 5 summarizes 1985 to 1994 data on the spatial distribution of chinook salmon spawning from aerial redd counts (data from CDFG). Aerial redd counts were available for 1985-87 and 1989-94 for fall run, for 1985-86, 1988-92 and 1994 for late fall-run, for 1987-94 for winter-run and for 1989-1993 for spring-run. Very few spring-run redds (less than 15 per year) were observed from 1989-1993, while no spring-run redds were observed in 1994. "Spring-run" in the mainstem Sacramento River are likely mostly hybrid spring & fall-run, with the migration timing of spring-run and the spawning timing of fall-run (Frank Fisher, CDFG, personal communication). Notable from this information is that around 29% of fall-run spawn below RBDD, with fall-run spawning as far downstream as Princeton. Table 6 gives the percentages of juvenile salmonids (Bontadelli 1991) passing RBDD for each month. Frank Fisher (CDFG, personal communication) stated that there is only a difference in timing of juvenile passage

Table 5
Spatial Distribution of Chinook Salmon Spawning

River Miles	Fall run	Late fall run	Winter run	Spring-run
298.5 - 302	8%	24%	2%	
296.5 - 298.5	13%	22%	43%	53%
285 - 296.5	15%	19%	27%	27%
276.2 - 285	12%	14%	10%	9%
266.7 - 276.2	15%	6%	6%	4%
257.8 - 266.7	6%	3%	6%	6%
243 - 257.8	2%	2%		
229.4 - 243	16%	6%	4%	1%
218.2 - 229.4	7%	2%	2%	
199.3 - 218.2	3%	1%		
184.3 - 199.3	2%	1%		
164 - 184.3	1%			

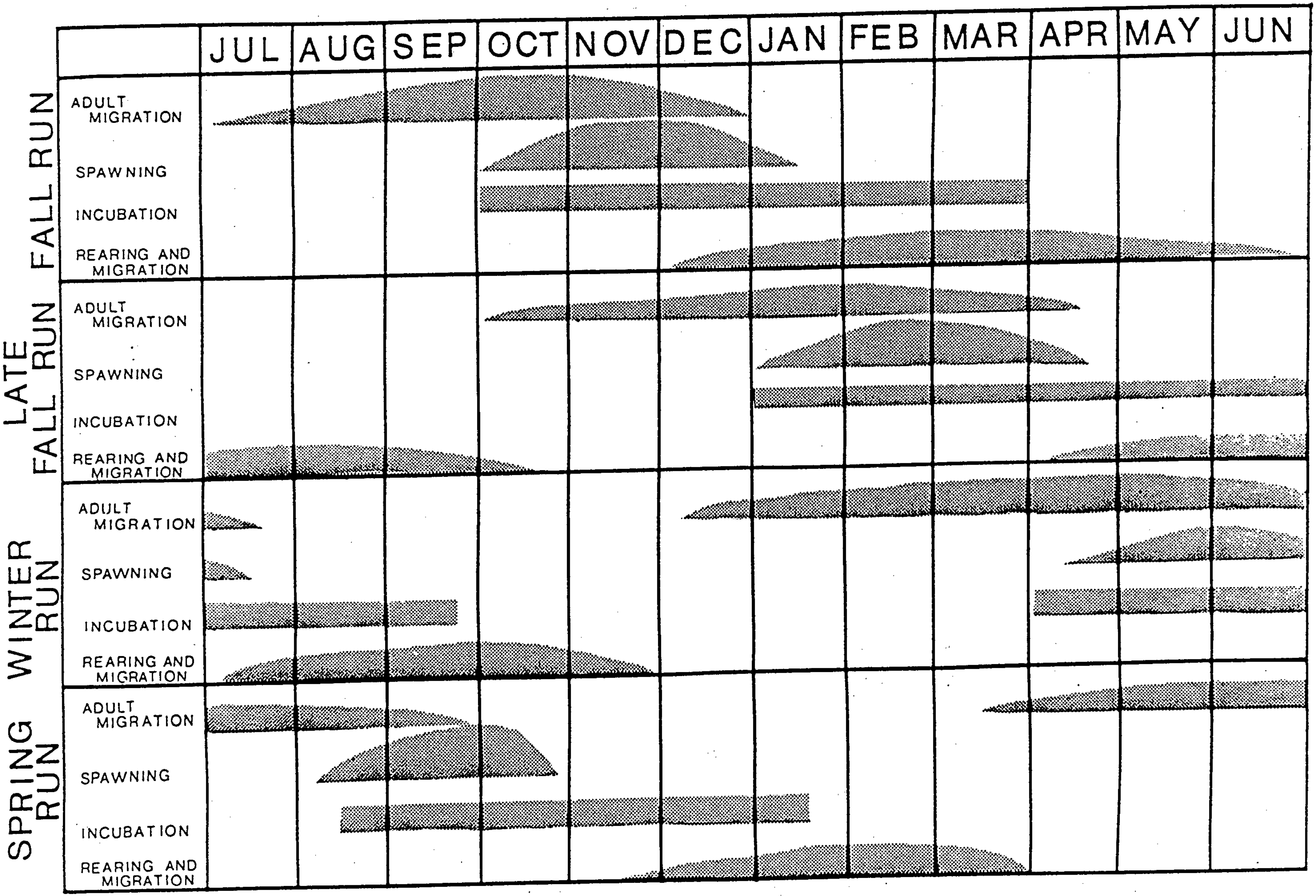
between wet and dry years for fall-run salmon. Figure 2 summarizes timing of all races, while Figures 3 through 6 (from Johnson et al 1992) summarize the distribution of juvenile salmon, based on beach-seining data. Table 7 gives the average size of juvenile salmon of each race (data from Johnson et al 1992). Outmigrating steelhead tend to be around 200 mm FL in size.

Maximum survival of incubating eggs occurs at water temperatures between 40 °F and 56 °F, while maximum survival of pre-emergent fry occurs at water temperatures between 40 °F and 58 °F (Vogel and Marine 1991). The U.S. Fish and Wildlife Service Chinook Salmon Temperature Mortality Model indicates that the typical amount of time for egg incubation is approximately one month, as is the typical amount of time between hatching and emergence. Daily survival versus temperature data in the U.S. Fish and Wildlife Service Chinook Salmon Temperature Mortality Model implies that the percent survival per month of eggs drops below 1% of maximum levels for monthly average water temperatures greater than 61.1 °F, while the percent survival per month of pre-emergent fry drops below 1% of maximum levels for monthly average water temperatures greater than 62.1 °F.

Table 6
Timing of Juvenile Salmonids Passing RBDD

Month	Fall run		Late fall run	Winter run	Spring run	Steelhead
	Wet	Dry				
Jan	34%	8%		10%	68%	5%
Feb	38%	8%		6%	5%	20%
Mar	7%	2%			1%	30%
Apr	6%	24%	52%		2%	30%
May	8%	43%	32%		1%	10%
Jun	6%	14%	7%			
Jul	1%	1%	1%	1%		
Aug			2%	7%		
Sep			1%	36%		
Oct			3%	24%		
Nov			2%	7%		
Dec				9%	23%	

Salmon Life Stages in the Sacramento River



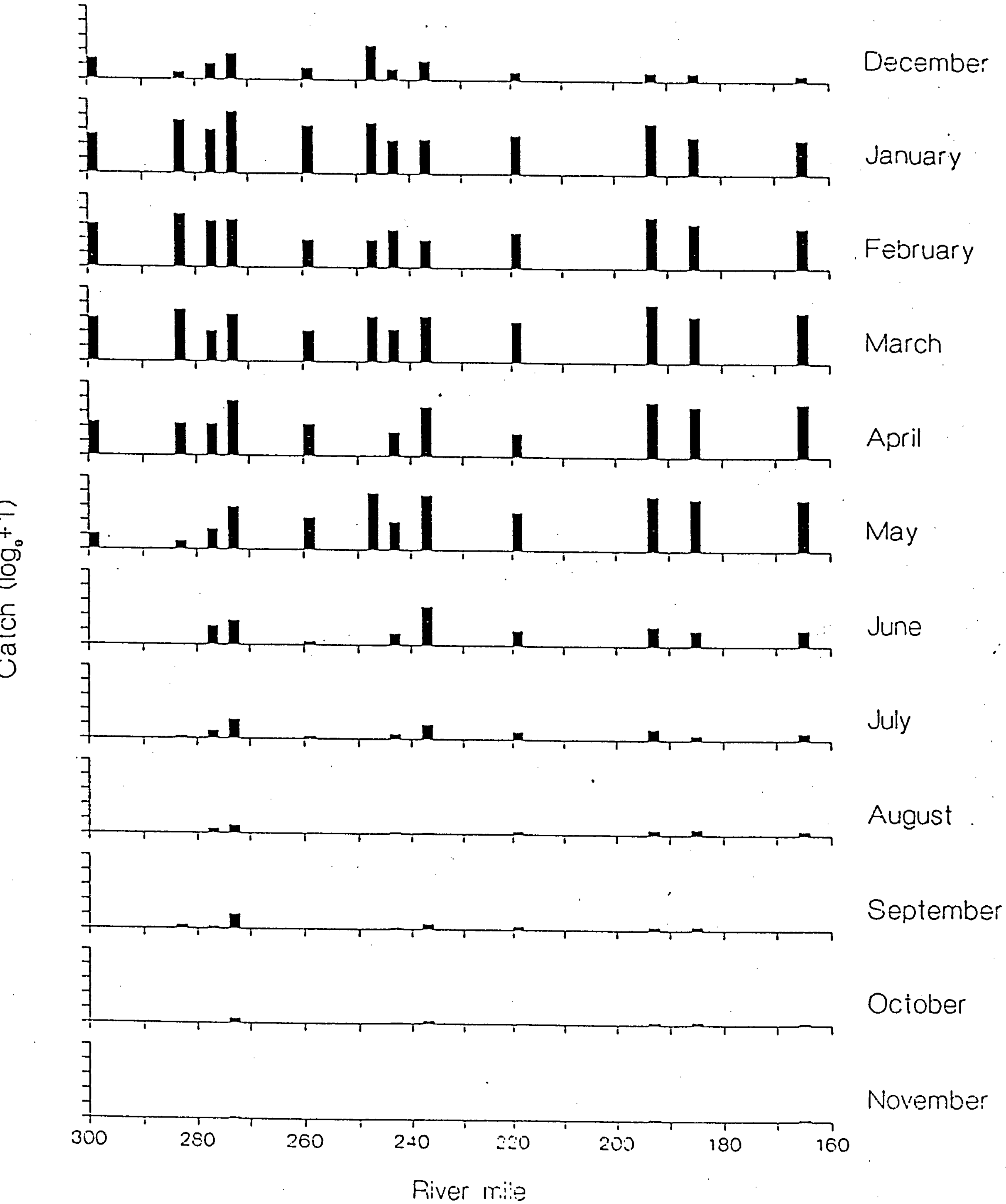


Figure 3.-Spacial and temporal distribution of fall-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e$(catch+1), so that values range from 1 to 5

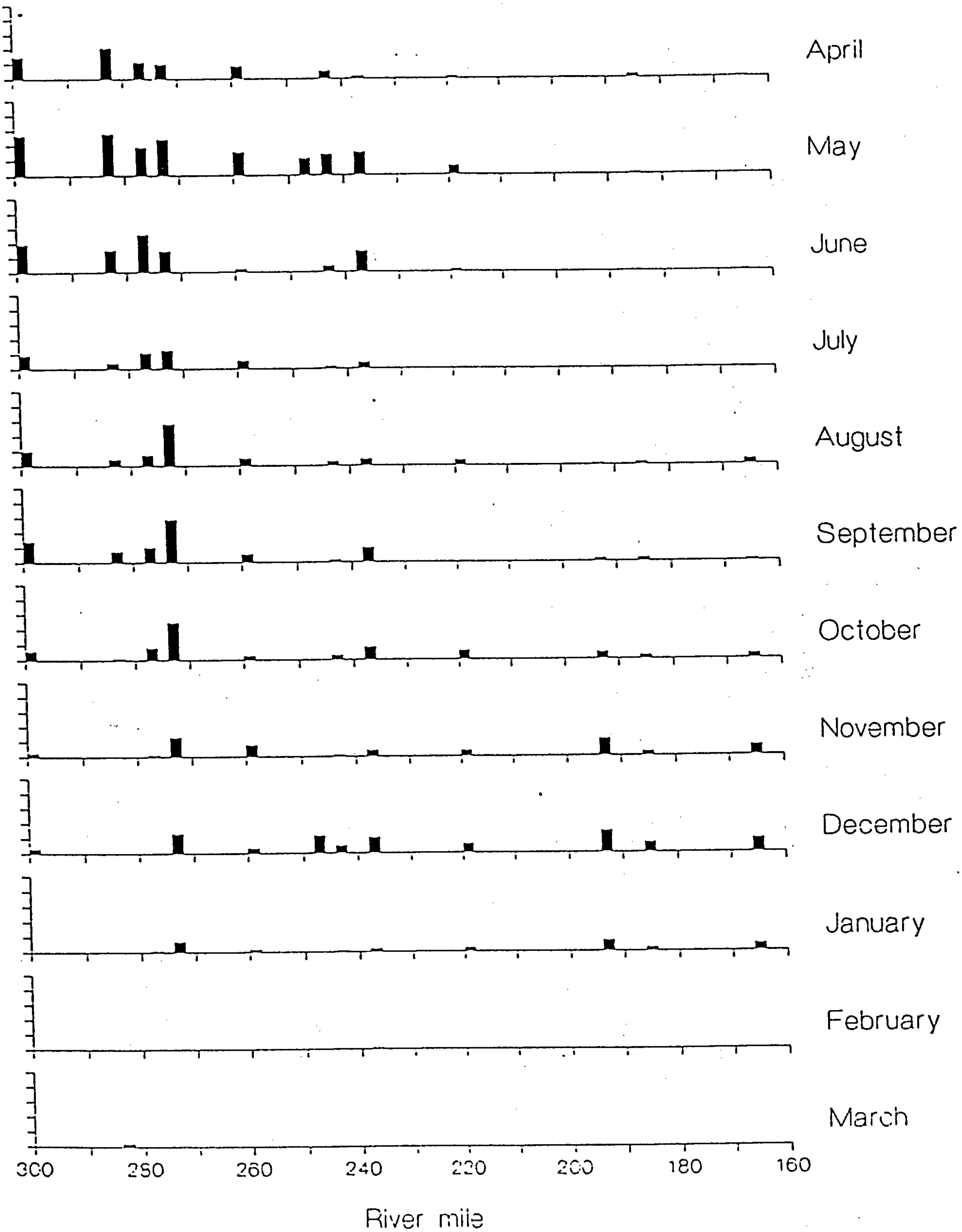


Figure 4.-Spacial and temporal distribution of late-fall-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e(\text{catch}+1)$, so that values range from 1 to 5.

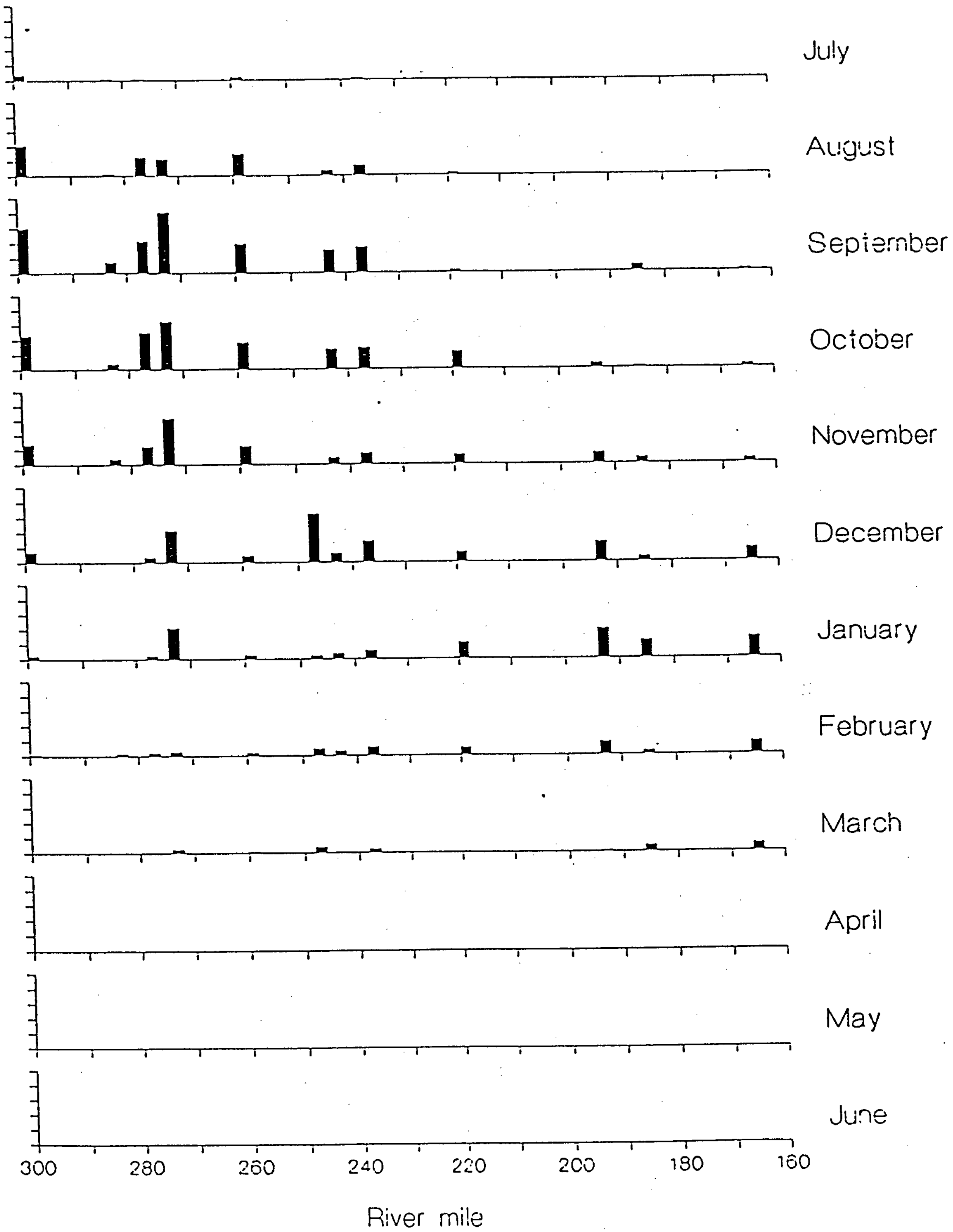


Figure 5.-Spacial and temporal distribution of winter-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e$(catch+1), so that values range from 1 to 5

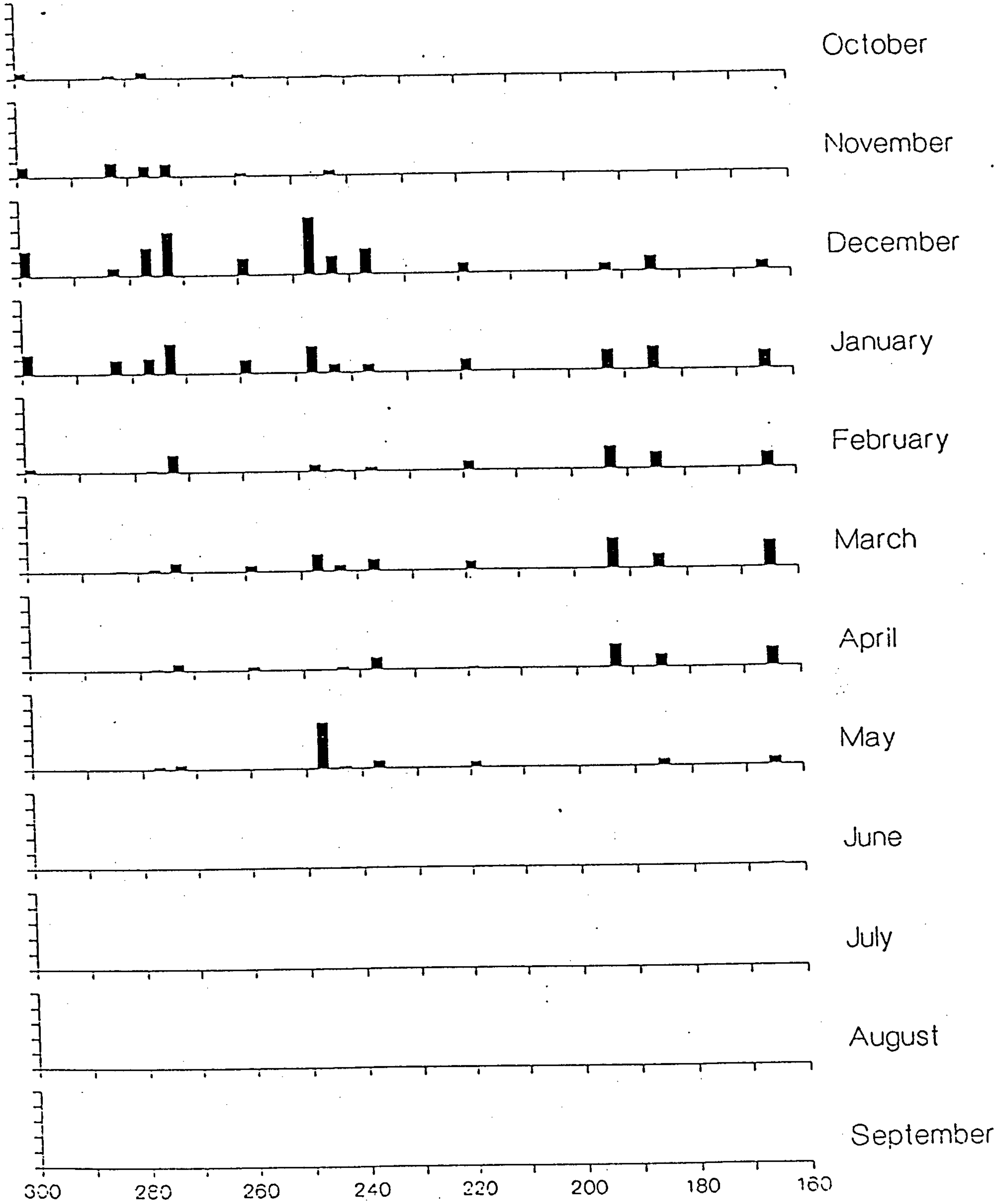


Figure 6.-Spacial and temporal distribution of spring-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation log(catch-1), so that values range from 1 to 5

Table 7
Average Size of Juvenile Chinook Salmon (mm)

Month	Fall run	Late fall run	Winter run	Spring run
Jan	45	166	89	54
Feb	37	200	110	65
Mar	45	244	136	80
Apr	54	37	166	99
May	65	34	181	122
Jun	80	41	244	150
Jul	99	49	37	181
Aug	122	59	34	219
Sep	150	73	41	270
Oct	181	89	49	34
Nov	219	110	59	37
Dec	37	136	73	45

Sturgeon

Juvenile sturgeon feed largely on zooplankton and small bottom invertebrates, while the diet of adult sturgeon includes fish and shellfish. Copepods and cladoceran zooplankton are particularly important food items for sturgeon larvae from 10 to 30 days after hatching (Brown 1995). Microhabitat use characteristics of sturgeon are given in Table 8 (data from Parsley et al 1993 and U.S. Fish and Wildlife Service 1994). Consistent with Table 8, Brown (1995) states that sturgeon spawn in water depths of 6 to 30 feet, velocities greater than 4 ft/s and over large gravel, rocks and small rubble substrate. Cover is important for sturgeon larvae during daytime (Brown 1995). HSI curves have been developed for white sturgeon spawning, and young-of-the-year and juvenile rearing, in the Columbia River (Parsley and Beckman 1994); a limited amount of Sacramento River spawning mat data (Schaffter 1994) could be used to modify Parsley and Beckman's (1994) white sturgeon spawning HSI curves for the Sacramento River through a Delphi analysis. Spawning seasons and temperatures for sturgeon are given in Table 9 (data from Moyle 1976 and U.S. Fish and Wildlife Service 1994). Similarly, Brown (1995) states that a majority of Sacramento River sturgeon spawn during March through May and possibly into June at temperatures of 50 - 64 °F. Important variables for sturgeon spawning are water velocity, depth, substrate and temperature; green sturgeon appear to require colder, cleaner (lower sediment levels) water for spawning than white sturgeon (U.S. Fish and Wildlife Service 1994). Prior to the construction of Shasta Reservoir, white sturgeon were found as far upstream as the Pit River (Healey 1987). After the construction of Keswick Dam, in the absence of RBDD, the primary spawning area in the Sacramento River was probably from Keswick Dam to Hamilton City for green sturgeon, and from Keswick Dam to Grimes (River Mile 125) for white sturgeon (Dave Kolhorst, CDFG, personal communication). Currently, most spawning has been observed in the Colusa (River Mile 144) to Grimes reach (Brown 1995). White sturgeon generally migrate upstream in the spring and migrate downstream in the summer and fall (Bell 1991). Green sturgeon probably migrate upstream for spawning in the Sacramento River between late February and late July (U.S. Fish and Wildlife Service 1994). Spawning conditions in the Sacramento River below RBDD (elevated temperatures and sediment levels) are probably suboptimal, compared with conditions upstream of RBDD (U.S. Fish and Wildlife Service 1994). Spring flows are important requirements for sturgeon as a spawning cue, as they affect spawning habitat area, and to disperse sturgeon larvae[1]; Sacramento River flows between Princeton and Colusa of 6,400 to 12,400 cfs have been identified as suitable for sturgeon spawning (Brown 1995).

Table 8
Microhabitat Use for Sturgeon Spawning

Species	Total Depth (ft)	Average Water Column Velocity (ft/s)	Substrate Type[2]
White sturgeon	>13	3 - 9.2	BO
Green sturgeon	>10	"relatively high"	CO

Table 9
Spawning Time and Temperature of Sturgeon

Species	Spawning Time	Spawning Temperature (°F)
White sturgeon	mid Mar to early June	50 - 75
Green sturgeon	March to July	46 - 57

[1] From hatching to four days posthatch, sturgeon larvae are pelagic and drift downstream.

[2] BE = bedrock, BO = boulder, CO = cobble, GR = gravel, SA = sand, SI = silt, MC = mud/soft clay, PD = plant detritus

Spring Pulse Flows

To minimize losses of young migrating salmon released from Coleman NFH at various locations on the upper Sacramento River, primarily at the GCID fish screens, Reclamation increased water releases from Keswick and Shasta Dams over a 3 day period in May for the years 1985 through 1989. Releases from Keswick Dam were increased from 9,000 to 14,000 cfs in 1985 (Vogel and Smith 1985). Fish releases from Coleman NFH were timed to result in nighttime passage of juveniles at RBDD. This effort appeared to be beneficial for hatchery salmon outmigration by reducing passage during the day, when predation rates are higher (U.S. Fish and Wildlife Service 1989).

Gravel Restoration

To improve chinook salmon spawning habitat in the Sacramento River in the first 13 miles below Keswick Dam, the California Department of Water Resources (CDWR) began a gravel restoration project in 1990 by adding spawning-sized gravel to the Sacramento River at eight sites (Bigelow 1992). CDWR added a total of approximately 100,240 yd^3 of gravel at the eight sites in 1990-91; gravel was dumped at three sites, where it would be available for high flows to disperse it throughout the channel, while the gravel was graded at the remaining five sites, so that the gravel would be immediately available as spawning habitat (Bigelow 1992). Previously, CDFG, with funding from Reclamation, had placed 16,000 yd^3 of spawning gravel in the Sacramento River at the mouth of Salt Creek (one of CDWR's sites) in 1988 and 8,000 yd^3 immediately below Keswick Dam (an additional site) in 1989. Thus, gravel has been added to a total of nine sites in the Sacramento River; in 1990, the NCVFRO mapped the suitability of substrate for spawning at four of these sites prior to the addition of spawning gravel, and at the Salt Creek site (Bigelow 1992). In addition, placement and utilization of the added gravel was monitored at all nine sites in 1990 through 1993 (Bigelow 1992, Bigelow 1993).

Central Valley Project Improvement Act

The Central Valley Project Improvement Act (CVPIA) (P.L. 102-575) was enacted in 1992 to (in part) address impacts of the CVP on fish, wildlife and associated habitats. This purpose is partially addressed by Section 3406(b)(1), which states that the Secretary of the Interior is authorized and directed to: "*develop ... and implement a program which makes all reasonable efforts to ensure that, by the year 2002, natural production of anadromous fish in Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991...*" Restoration plans have been prepared under this program (the Anadromous Doubling Program) for salmon and steelhead, for both the upper Sacramento River and its tributaries, and for sturgeon, American shad and striped bass.

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APPENDIX B

Sacramento River Hydrology

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Upper Sacramento River IFIM Study Scoping Report

SACRAMENTO RIVER HYDROLOGY

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May 1995

The main purpose of this report is to recommend stream segments for the Sacramento River IFIM Study, based on changes in stream flow. Bovee (1995) recommends that the cumulative change in flow within a segment be less than 10%. Another purpose of this report is to gain some understanding of the effects of accretions on Sacramento River flows in different months. Historical monthly average Sacramento River flows were synthesized below each gaged tributary or diversion (Table 1) from Keswick Dam (River Mile 302) to Butte City (River Mile 168.6) from October 1974 through September 1993. This time period was selected to allow for the examination of year-to-year variations in water type, while staying within a period with relatively few changes in Central Valley Project features (significant agricultural diversions at Red Bluff Diversion Dam (RBDD) started in the spring of 1975). I chose a monthly time step to facilitate the examination of this relatively long time period and minimize the effects of travel time on mass-balancing calculations. The geographic boundaries were selected because Keswick Dam is the upstream limit for migrating salmonids, and virtually all salmon spawn above Butte City.

Historic flow records were available for six Sacramento River gages and all of the larger tributaries (Table 1). However, there are significant ungaged drainage areas, both on gaged tributaries downstream of the gage and on at least 21 smaller ungaged tributaries (many of these tributaries only have flows during the wet season). In addition, a significant number

Table 1
Gaging Stations

River Mile	Description	Drainage Area[1]	Miles Upstream of Mouth	Period of Record	Agency	Gage No.
301.4	Keswick gage	---	---	1938-present	USGS	3705
298.5	ACID Diversion	---	---	1974 (or earlier) -present	USBR/USGS	3707
289.3	Clear Creek	---	10.4[2]	1940-present	USGS	3720
284.7	Churn Creek	9.3	15	1961-1972	USGS	37205
280.2	Cow Creek	425	2.9	1919-present	USGS	3740
277.6	Bear Creek	75.6	2.9	1960-1967	USGS	3741
273.3	Cottonwood Creek	927	2.5	1940-present	USGS	3760

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[1] Numbers in this column are drainage area above gage, for gages for which such information was available; otherwise, numbers are drainage areas of entire watersheds.

[2] Diversion downstream of gage approximately 10 cfs Apr-Oct, 5 cfs Nov-Mar (Harry Rectenwald, CDFG, personal communication).

270	Battle Creek	357	5.7	1961-present	USGS	37655
260.3	Bend Bridge Gage	---	---	1892-present	USGS	3771
253	Paynes Creek	92.7	0.4	1950-1966	USGS	3775
244.8	Reeds Creek	74.7	7	1985-present	CDWR	A0-0628
243.1	Red Bank Creek	93.5	3	1976-present	CDWR	A0-3460
243	RBDD Diversions	---	---	1960-present	USBR	---
235	Antelope Creek	123	9.7	1941-1982	USGS	3790
235	Antelope Creek	246	0.3	1948-1957	CDWR	A0-4520
230.4	Elder Creek	92.4	35	1948-present	USGS	3795
230.4	Elder Creek	136	3.5	1949-69, 77-79	USGS	3805
230	Mill Creek	131	5.5	1928-present	USGS	3815
230	Mill Creek/ NF Mill Creek	259	1.0/1.7	1948-1957	CDWR	A0-4420/ A0-4440
226	Thomes Creek	203	25	1920-present	USGS	3820
226	Thomes Creek	284	7	1977-1980	USGS	38209
219.6	Deer Creek	208	11.7	1939-present	USGS	3835
219.6	Deer Creek	236	2	1948-1958	CDWR	A0-4320
218.3	Woodson Br. Gage	---	---	1976-present	CDWR	A0-2700
206.2	GCID Diversion	---	---	1922-1992	USBR	---
199.3	Hamilton City Gage	---	---	1976-present	CDWR	A0-2630
193	Big Chico Creek	72.2	11	1931-1986	USGS	3840
193	Big Chico Creek	326	1.5	1948-56	CDWR	A0-4245
193	Mud Creek	49	5	1965-present	CDWR	A0-4242
190	Stony Creek	738	25	1955-present	USGS/USBR	3880
190	Stony Creek	777	6	1940-1973	USGS	3885
184	Ord Ferry Gage	---	---	1976-present	CDWR	
168.6	Butte City Gage	---	---	1921-present	USGS	3890

of tributaries lose flow going downstream, particularly in the summer. For these reasons, I used gaging records from the downstream-most gage on each gaged tributary to synthesize Sacramento River flows. Diversion records were available for the three largest diversions (ACID, RBDD and GCID) for the entire study period. Diversion records were only available for numerous other (generally fairly small) diversions for 1976 (California Department of Water Resources 1977).

The first step in synthesizing Sacramento River flows at ungaged locations was to develop relationships, using regression techniques, between tributary gages where there were flow records for the entire study period and those for which there were records only for a portion of the study period or from prior to October 1974. Bovee (1995) recommends using a log-log regression to develop relationships between gages, and that the multiple-r value should be greater than 0.9 for the regressions. Where possible, flows for a gage were estimated from flows on another gage on the same stream. When this was not possible, flows were estimated from Cow Creek for east-side tributaries and from Elder Creek (gage no. 3805) for west-side tributaries; these two streams had a relatively long period of record, including the entire study period. Log-log regressions were used in most cases where they produced a multiple-r value of greater than 0.9. However, linear regressions produced much higher multiple-r values for many tributaries, particularly intra-tributary regressions and regressions of lower-flow tributaries. Linear regressions were only used to synthesize tributary flows where positive values were calculated from the equation; where the equation predicted negative values, predicted flows were set equal to zero. This procedure mimics flow conditions in many west-side tributaries, where downstream locations have no flow when flows at upstream locations fall below some critical value, as a result of channel losses. Table 2 shows the regressions that were used to synthesize tributary flows for months in which measured flows were not available. All of the regressions had multiple-r values greater than 0.9 except for Churn Creek. Although a log-log regression produced a higher multiple-r value for Churn Creek, I used the linear regression, because it was more accurate at predicting high flows; high Churn Creek flows would have the largest effect on Sacramento River flows. Flows near the mouth of Mill Creek were calculated by adding together flows for Mill Creek gage no. A0-4420 and flows for North Fork Mill Creek; the North Fork of Mill Creek is a regulated diversion from Mill Creek to the Sacramento River. Stony Creek flows were set to zero in all months when there were diversions at GCID, since GCID's gravel dam across Stony Creek, in place whenever diversions are being made, results in no flow from Stony Creek to the Sacramento River. Using the above techniques, I was able to synthesize flows on most of the larger tributaries within 10 miles of their confluence with the Sacramento River.

The next step was to use a mass-balance approach between Sacramento River gages to determine what portion of the change in flow between gages could not be explained by gaged tributaries and diversions. This portion, hereafter referred to as "ungaged flow," could be due to flow from ungaged tributaries or ungaged portions of gaged tributaries, ungaged diversions, regression errors, tributary channel losses, or gaging errors. When the calculated ungaged flow was positive (ie accretions), the ungaged flow was divided up between reaches by

Table 2
Regression Equations Used to Synthesize Tributary Flows

Regression Equation	multiple-r	n
$Churn = -68 + 0.586 \times Cow$	0.87	72
$\ln(Bear) = -0.197 + 0.723 \times \ln(Cow)$	0.96	96
$\ln(Paynes) = -6.726 + 1.617 \times \ln(Cow)$	0.94	204
$Reeds = -4.86 + 0.291 \times Elder_{3795}$	0.93	105
$Red\ Bank = -11.415 + 0.648 \times Elder_{3795}$	0.95	204
$\ln(Antelope_{3790}) = 1.58 + 0.538 \times \ln(Cow)$	0.93	394
$Antelope_{A0\text{-}4520} = -36.56 + 0.795 \times Antelope_{3790}$	0.91	99
$\ln(Elder_{3805}) = -2.728 + 1.487 \times \ln(Elder_{3795})$	0.92	254
$Mill_{A0\text{-}4420} + North\ Fork\ Mill = -90.54 + 1.077 \times Mill_{3815}$	0.97	107
$Thomes_{38209} = -9.823 + 1.102 \times Thomes_{3820}$	0.99	36
$Deer_{A0\text{-}4320} = -63.464 + 0.956 \times Deer_{3835}$	0.98	72
$\ln(Big\ Chico_{3840}) = 0.628 + 0.666 \times \ln(Cow)$	0.92	442
$Big\ Chico_{A0\text{-}4245} = -13.52 + 0.852 \times Big\ Chico_{3840}$	0.96	77
$Stony_{3885} = -103.18 + 1.088 \times Stony_{3880}$	0.99	216

multiplying the ungaged flow by the proportion of ungaged drainage areas within the reach[3]. Ungaged drainage areas for each reach (Table 3) were calculated by the sum of drainage areas for ungaged tributaries (from California Department of Water Resources 1962) and the ungaged area of gaged tributaries (calculated by subtracting the drainage area in Table 1 from the total drainage area for that tributary from California Department of Water Resources 1962). When the calculated ungaged flow was negative (ie losses), the flow was divided up between reaches based in part on data for ungaged diversions from 1976 from California Department of Water Resources 1977. Three possible situations were: 1) for months (November through February) or areas between Sacramento River gages (Bend Bridge to Hamilton City) with negligable ungaged diversions, the ungaged flow was divided equally

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3 This appears to be a good assumption, since there is a very strong positive relationship (multiple-R = 0.97) between the average flow for 1974-93 and the drainage area of gaged tributaries.

Table 3
Ungaged Areas of Sacramento River Reaches

Reach	Total Ungaged Area (mi^2)
Keswick - ACID	28.7
ACID - Clear	36.8
Clear - Churn	54.9
Churn - Cow	168.1
Bear - Cottonwood	99.6
Battle - Bend Br.	48.7
Bend Br. - Paynes	10.3
Paynes - Reeds	98.6
Reeds - Red Bank	21.5
Antelope - Elder	114.5
Mill - Thomes	86
Thomes - Deer	41.8
Woodson Br. - GCID	132
Hamilton City - Big Chico	150
Big Chico - Stony	167

between reaches; 2) when the total diversions in that month in 1976 between Sacramento River gages was greater than the calculated ungaged flow, the ungaged flow was divided up between reaches with diversions in 1976 proportional to the diversions in 1976; and 3) when the total diversions in that month in 1976 between Sacramento River gages was less than the calculated ungaged flow, the 1976 diversions were applied to the respective reaches, with the difference between total diversions and ungaged flow divided equally between all reaches.

The final step in synthesizing Sacramento River flows was to start at Keswick gage each month and go downstream, adding flow from gaged tributaries and ungaged flows allocated to each reach, and subtracting gaged diversions. The results of the flow synthesis are summarized in Table 4 and Figures 1 through 12. The denominator used to calculated the cumulative percentage flows in Table 4 was reset whenever they went over 110% (greater than 10% change) and after major diversions. The years shown in each figure are those with the lowest and highest flows.

Table 4
Average Synthesized Sacramento River Flows (October 1974 - September 1993)

Location[4]	Average Flows (cfs)	Cumulative Percent Change in Flows
Keswick gage	9,169	---
ACID Diversion	9,001	98%
Clear Creek	9,122	101%
Churn Creek	9,452	105%
Cow Creek	10,156	113%
Bear Creek	10,217	101%
Cottonwood Creek	11,069	109%
Battle Creek	11,526	113%
Bend Bridge Gage	11,541	100%
Paynes Creek	11,631	101%
Reeds Creek	11,839	103%
Red Bank Creek	11,925	103%
RBDD	11,299	95%
Antelope Creek	11,365	101%
Elder Creek	11,683	103%
Mill Creek	11,892	105%
Thomes Creek	12,362	109%
Deer Creek	12,659	112%
Woodson Br. Gage	12,655	100%
GCID Diversion	11,902	94%
Hamilton City Gage	11,856	100%
Big Chico Creek	11,826	99%
Stony Creek	12,053	101%
Butte City Gage	11,736	99%

[4]Location is at the gage or just downstream of the tributary or diversion.

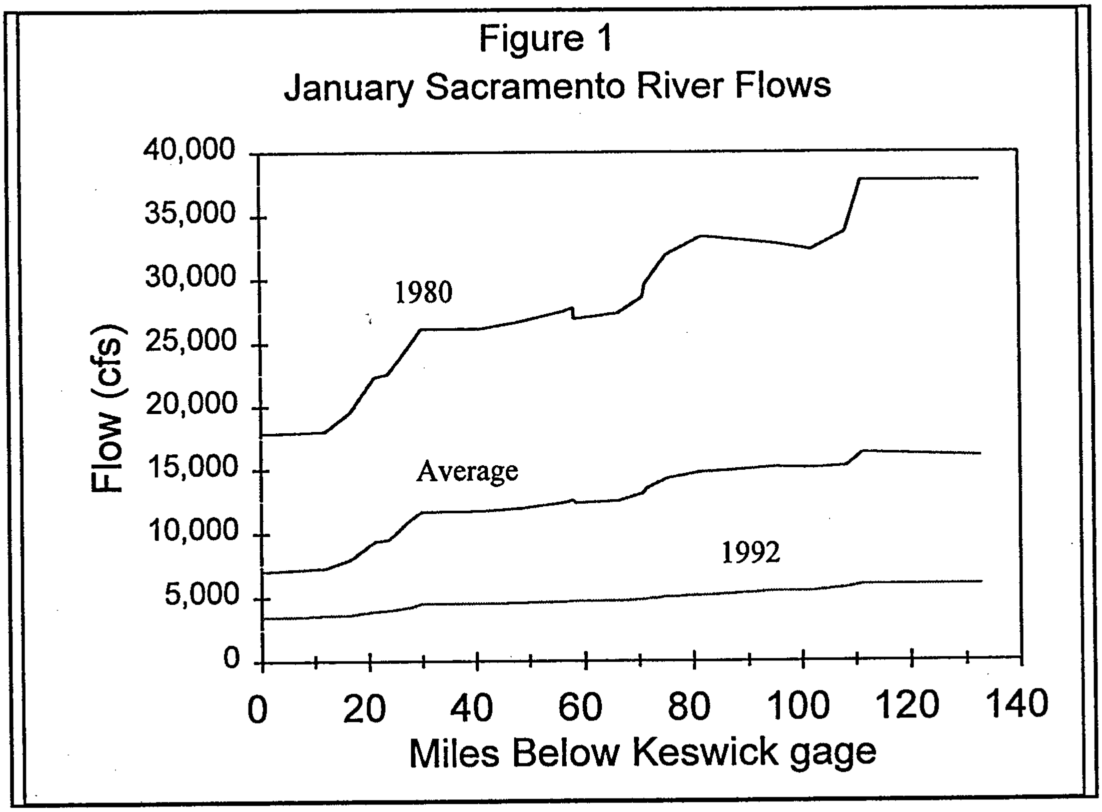


Figure 1
January Sacramento River Flows
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Flow (cfs)
1980
Average
1992
0
20
40
60
80
100
120
140
Miles Below Keswick gage

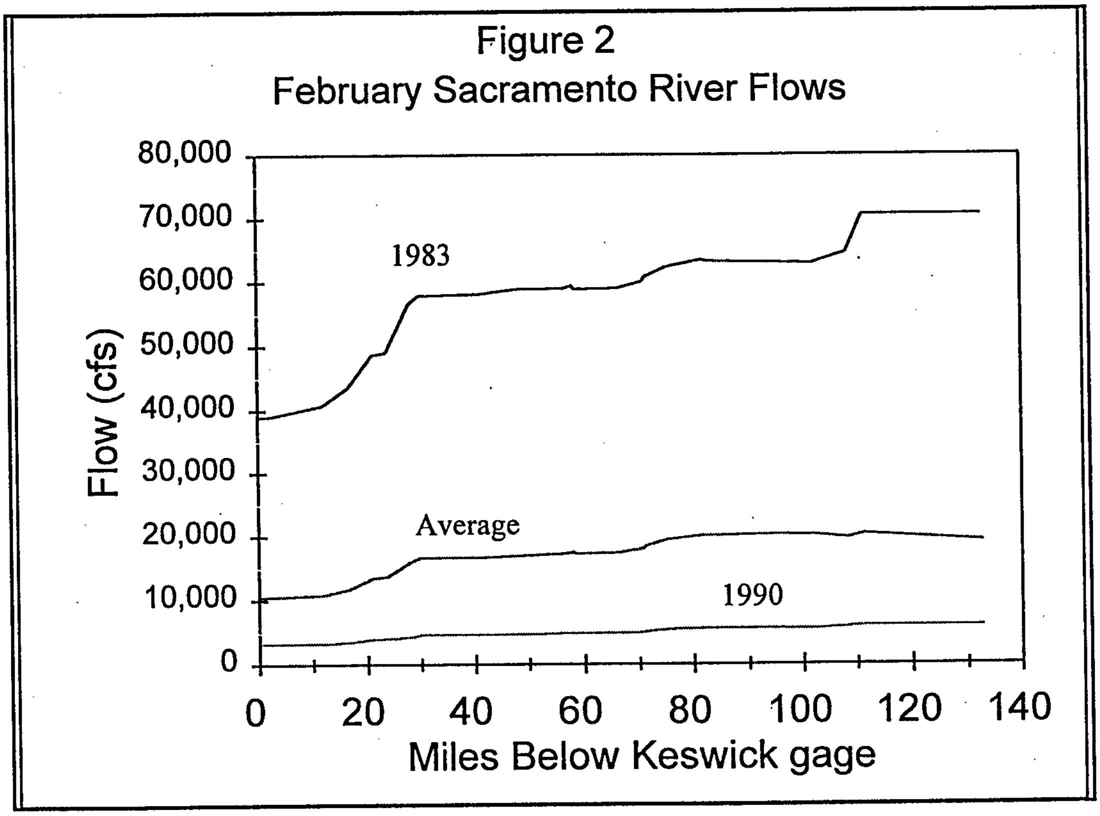


Figure 2
February Sacramento River Flows
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Flow (cfs)
1983
Average
1990
0
20
40
60
80
100
120
140
Miles Below Keswick gage

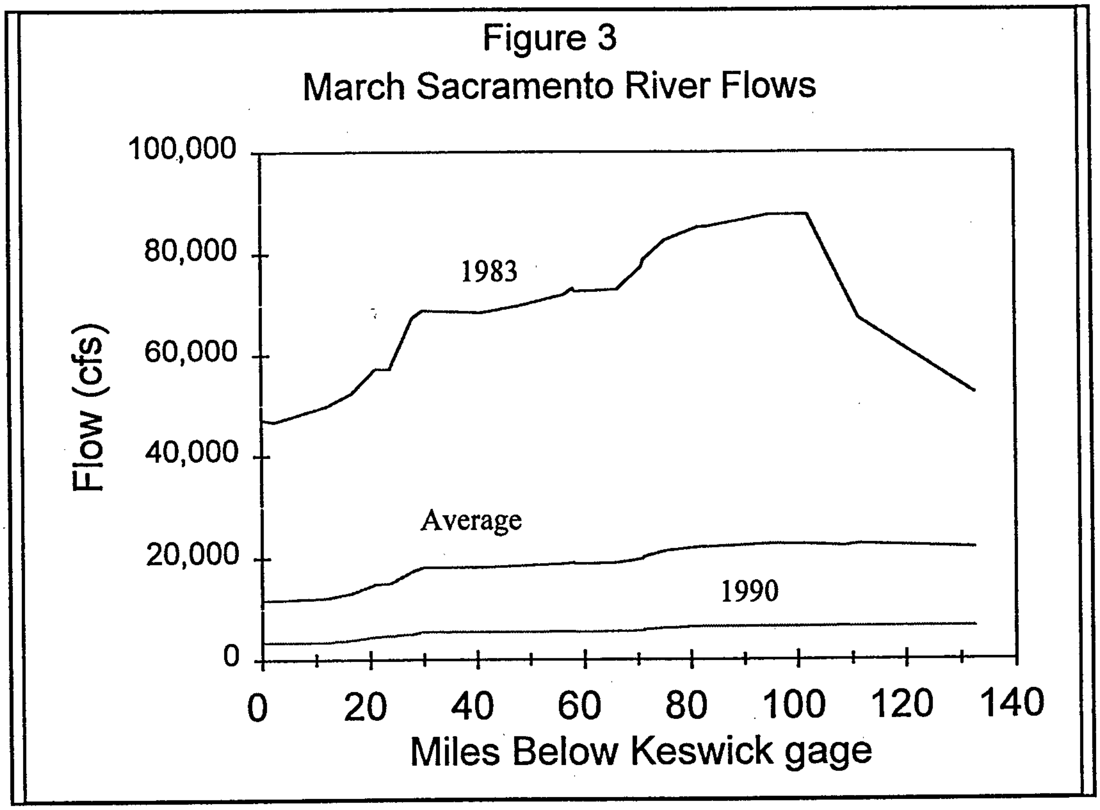


Figure 3
March Sacramento River Flows
100,000
80,000
60,000
40,000
20,000
0
1983
Average
1990
Flow (cfs)
0
20
40
60
80
100
120
140
Miles Below Keswick gage

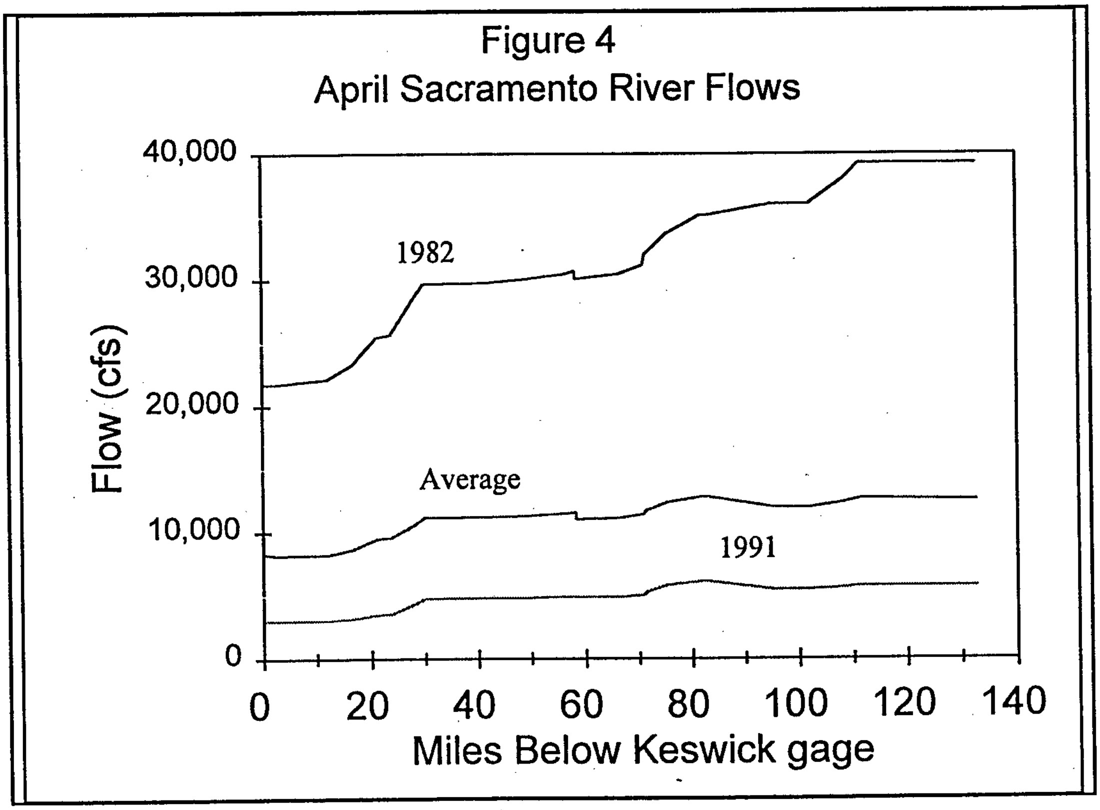


Figure 4
April Sacramento River Flows
40,000
30,000
20,000
10,000
0
1982
Average
1991
Flow (cfs)
0
20
40
60
80
100
120
140
Miles Below Keswick gage

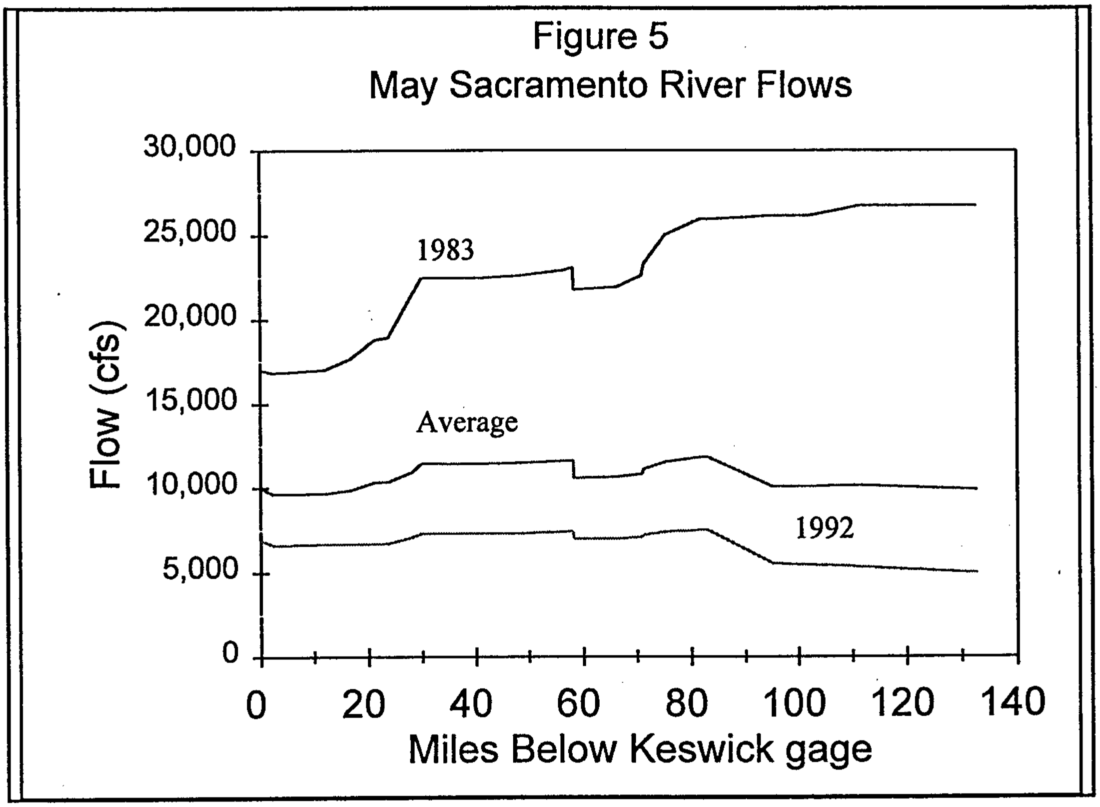


Figure 5
May Sacramento River Flows
30,000
25,000
20,000
15,000
10,000
5,000
0
Flow (cfs)
1983
Average
1992
0
20
40
60
80
100
120
140
Miles Below Keswick gage

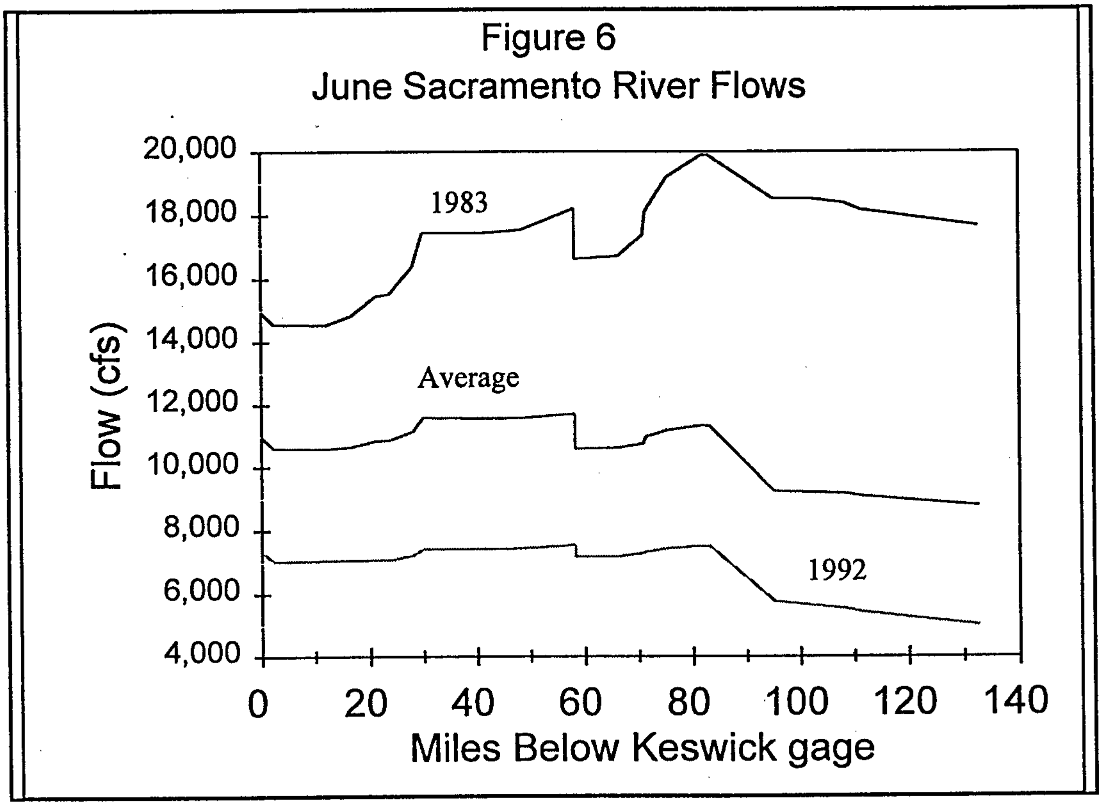


Figure 6
June Sacramento River Flows
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
Flow (cfs)
1983
Average
1992
0
20
40
60
80
100
120
140
Miles Below Keswick gage

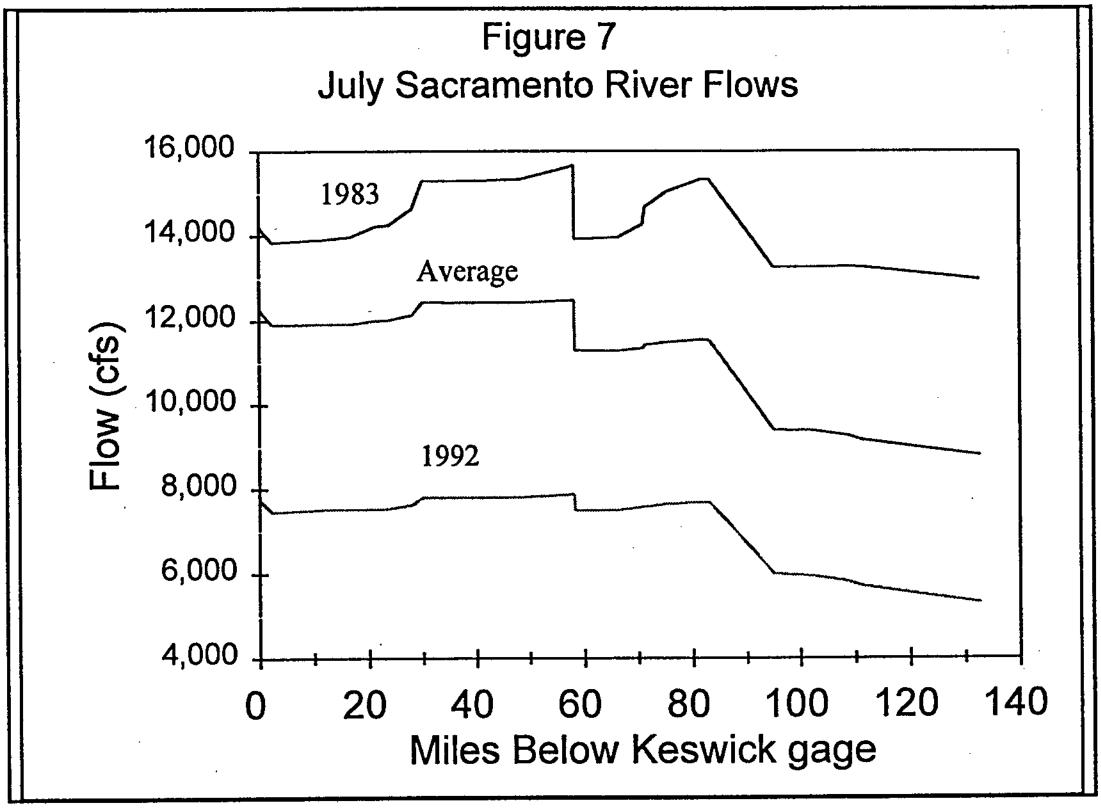


Figure 7
July Sacramento River Flows
16,000
14,000
12,000
10,000
8,000
6,000
4,000
Flow (cfs)
1983
Average
1992
0
20
40
60
80
100
120
140
Miles Below Keswick gage

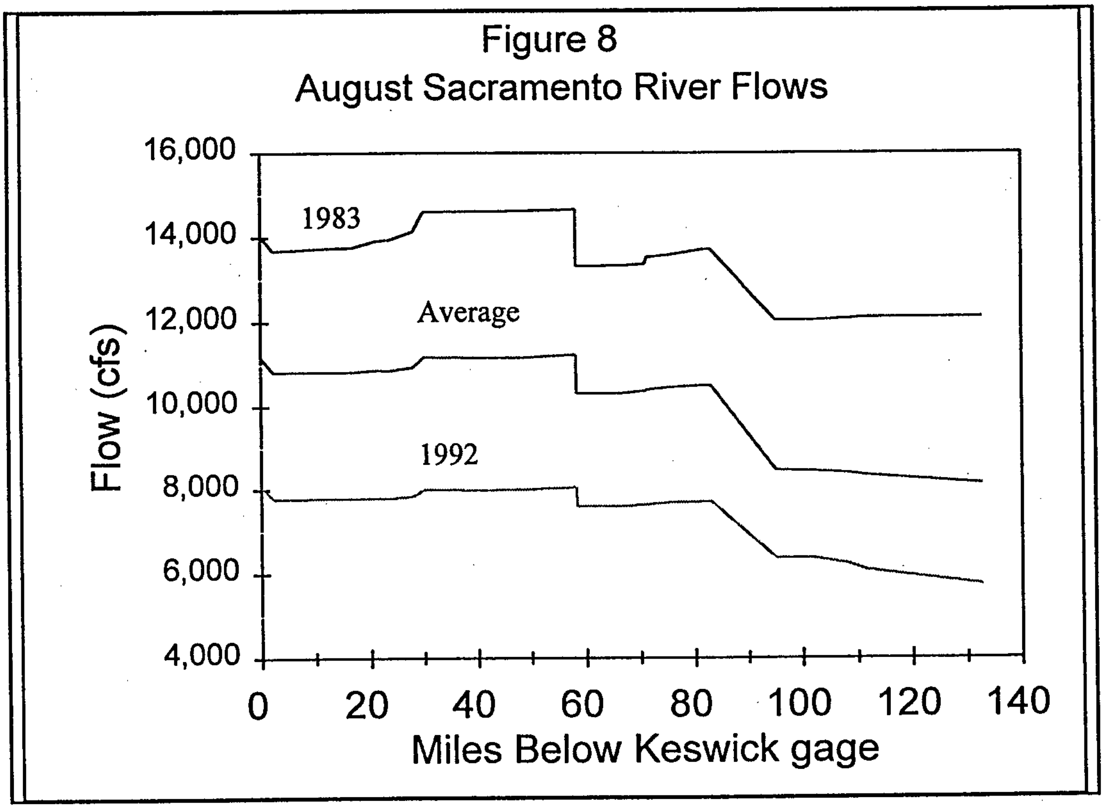


Figure 8
August Sacramento River Flows
16,000
14,000
12,000
10,000
8,000
6,000
4,000
Flow (cfs)
1983
Average
1992
0
20
40
60
80
100
120
140
Miles Below Keswick gage

Figure 9
September Sacramento River Flows

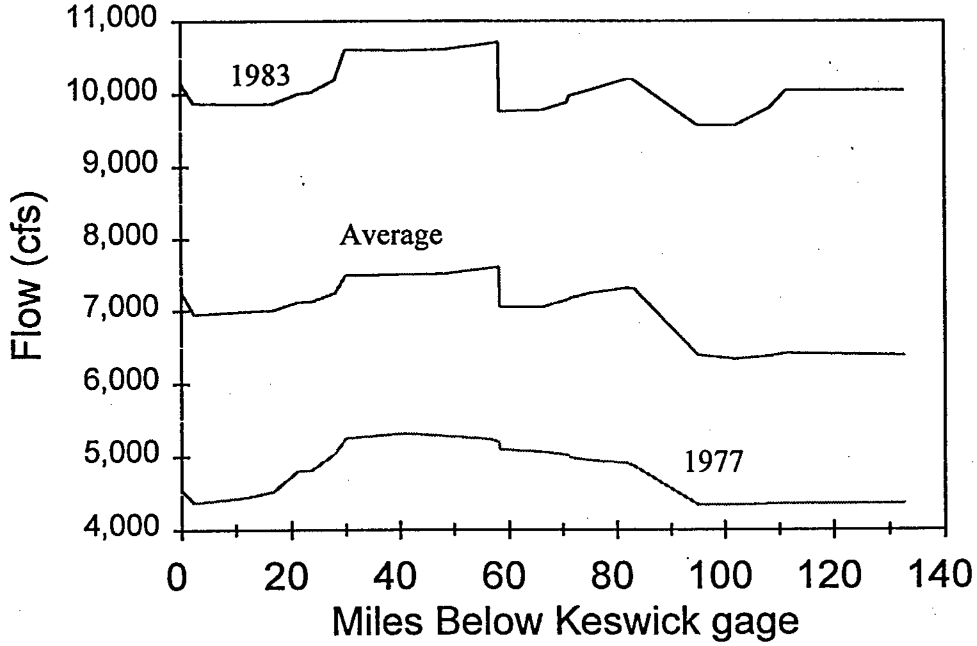


Figure 10
October Sacramento River Flows

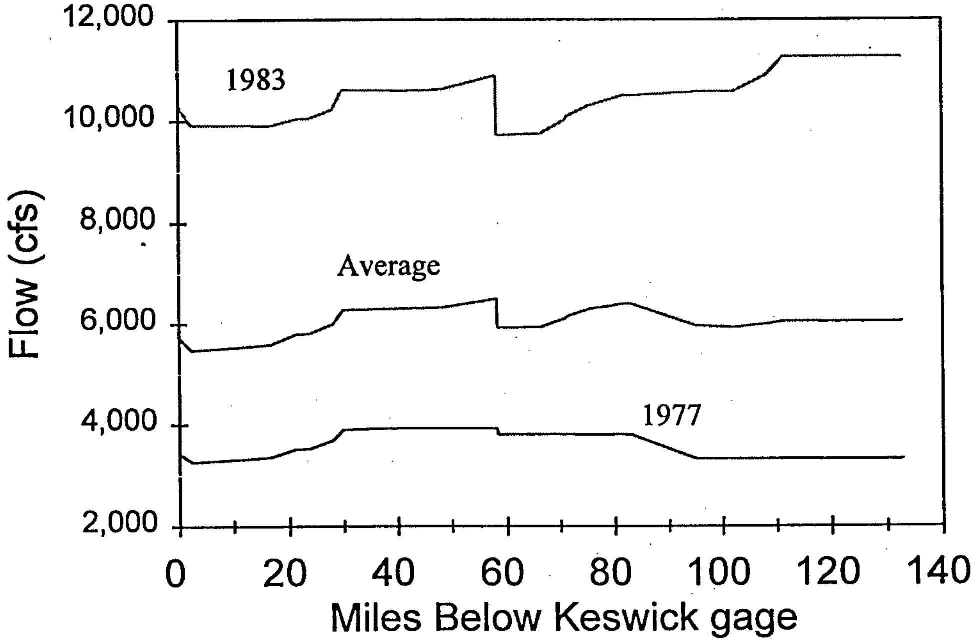


Figure 11
November Sacramento River Flows

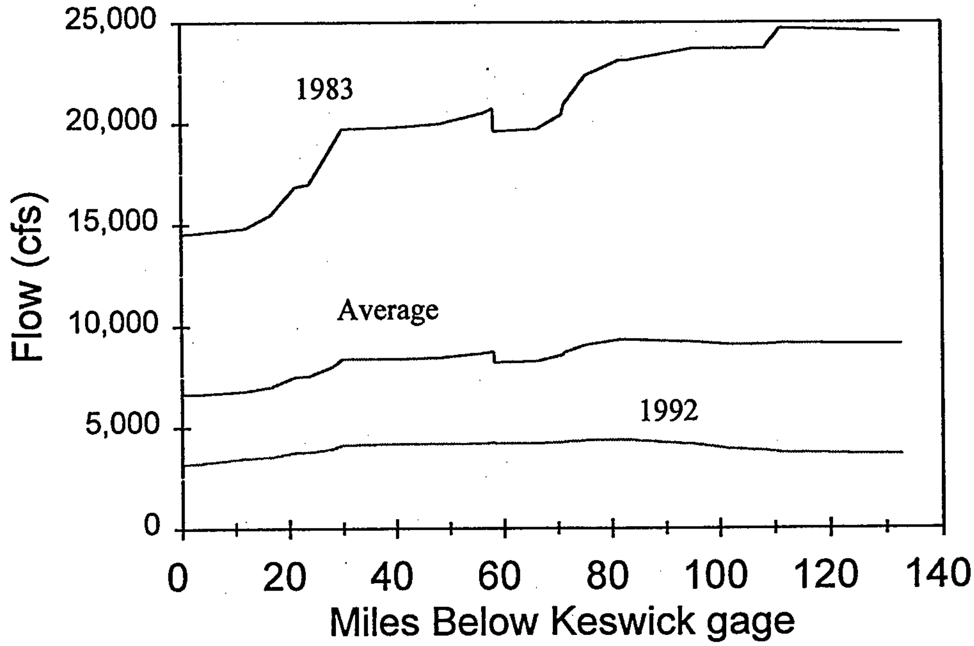
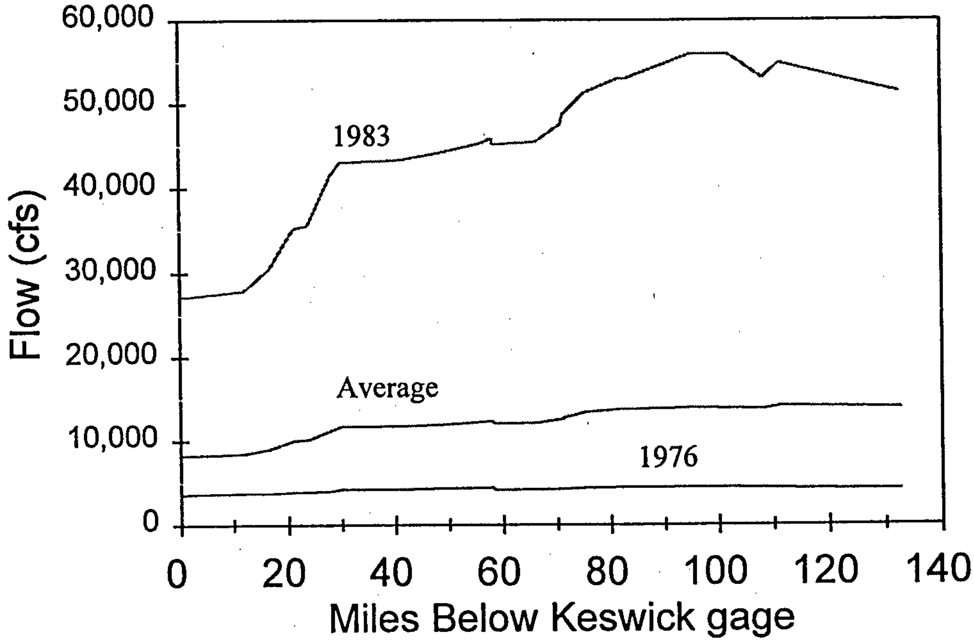


Figure 12
December Sacramento River Flows



Although the ACID diversion does not result in a 10% change in flow, the Keswick-ACID reach should be a separate segment, since this area is not typical of the rest of the Sacramento River (California Department of Water Resources 1993), with regards to channel morphometry. Based on the 10% change in flow criteria, ACID-Cow Creek and Cow Creek-Battle Creek should be separate segments. The 6.5 miles above RBDD which are inundated by Lake Red Bluff four months of the year should be a separate segment because of this periodic inundation. Based on the 10% change in flow criteria, RBDD-Deer Creek should be a separate segment. Although GCID does not result in a 10% change in flow on a year-round basis, it does cause an average 14% decrease in Sacramento River flows during April-October (the main months that flows are diverted at GCID); accordingly, Deer Creek-GCID and GCID-Butte City should be separate segments. If sturgeon spawning is addressed in the Sacramento River instream flow study, another stream segment would be the main spawning area for sturgeon, Grimes-Colusa (River Miles 125-144). Table 5 summarizes the stream segments that could be used in the Sacramento River instream flow study, based on the above discussion.

Table 5
Potential Stream Segments

Stream Segment	River Miles
Keswick Dam - ACID	302 - 298.5
ACID - Cow Creek	298.5 - 280.2
Cow Creek - Battle Creek	280.2 - 270
Battle Creek - above Lake Red Bluff	270 - 249.5
Lake Red Bluff	243 - 249.5
RBDD - Deer Creek	219.6 - 243
Deer Creek - GCID	206.2 - 219.6
GCID - Butte City	168.6 - 206.2
Colusa - Grimes	144 - 125

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APPENDIX C

Chinook Salmon HSI Curves

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Upper Sacramento River IFIM Study Scoping Report

CHINOOK SALMON HSI CURVES

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Division of Ecological Services
Sacramento, California

June 1995

The purpose of this report is to help in the sampling design for habitat use measurements. The recommended approach for collecting data to develop habitat suitability index (HSI) curves has changed from habitat preference, calculated by dividing habitat use by habitat availability, to habitat use, with availability taken into account through an equal-effort sampling design, where an equal area of each mesohabitat type is sampled (Bovee 1995). HSI curves developed using an equal-effort sampling design tend to be closer to curves derived from habitat use than from habitat preference (Bovee 1995). The HSI curves and criteria used in the California Department of Water Resource's (CDWR) Upper Sacramento Instream Flow Study (Figures 1, 2, 3, 5 and 6) are based on habitat preference (California Department of Water Resources 1993).

To test the sensitivity of the PHABSIM modeling results to habitat use versus habitat preference curves, I derived fall-run chinook salmon spawning habitat use curves from the California Department of Fish and Game's (CDFG) Sacramento River habitat use data (used to derive the habitat preference curves used by CDWR), as follows. For spawning, all fall-run data for which there were measurements of all three habitat parameters (depth, velocity and substrate) were pooled. Frequency distributions for depth and velocity were developed and input into the CURVE utility in PHABSIM. HSI curves were then derived with CURVE using a fourth order exponential curve fit for depth and a second order exponential curve fit for velocity. The depth HSI curve was assumed to remain at 1.0 for depths greater than the depth at which the curve fit reached 1.0. Substrate HSI criteria were calculated by dividing the frequency of habitat use for each combination of dominant and subdominant size classes (Table 1) by the combination of dominant and subdominant size classes with the highest frequency of habitat use. The resulting HSI spawning curves and criteria are shown in Figures 1, 2 and 3. While the HSI depth curves for use and preference are quite similar, the HSI velocity curve for use indicates much higher suitable velocities than the HSI preference curve, probably due to the low availability of lower velocities. There were also substantial differences in the HSI substrate use and preference criteria, presumably due to different availabilities of various combinations of dominant and subdominant substrate size classes.

The above HSI fall-run chinook salmon spawning curves and criteria, along with fall-run chinook salmon spawning HSI curves developed for the Lower American (U.S. Fish and Wildlife Service 1985), Feather (California Department of Water Resources 1994) and Yuba (Beak Consultants Inc 1990) Rivers were used with CDWR's Sacramento River PHABSIM data decks for their Reach 1 (ACID-Cottonwood Creek) to see what differences in weighted useable area curves resulted from different HSI curves and criteria. HSI criteria for fall-run chinook salmon spawning for the Lower American, Feather and Yuba Rivers would be most likely to be transferable to the Sacramento River since these rivers are in the Sacramento River basin and have flows in the same order of magnitude as the Sacramento (annual average flows for the Lower American, Yuba and Feather Rivers are, respectively, 3,700 cfs, 2,600 cfs and 4,600 cfs, while the annual average flows for the Sacramento River in CDWR's Reach 1 are in the range of 10,000 to 12,000 cfs). For the Feather River, the depth curve with no decrease in suitability for deep waters was used, and for the Yuba River, the depth curve was modified to have no decrease in suitability for deeper waters, to be as comparable as possible to the Sacramento River curve sets. Substrate HSI criteria for the Lower American, Feather and Yuba Rivers were adapted for use with CDWR's Sacramento River data decks by translating the substrate size classes used in these criteria to the substrate classes in Table 1. None of these three criteria sets explicitly

Table 1
Substrate Codes

Substrate Code[1]	Definition
1	Silts or fine clay
2	Sand or fine gravel less than ½" in diameter
3	Small gravel between ½" and 2" in diameter
4	Large gravel between 2" and 6" in diameter
5	Cobbles between 6" and 12" in diameter
6	Boulders over 12" in diameter
7	Compacted clay
8	Bedrock
9	Undefined

considered subdominant size classes, so the same suitability was assumed to apply for a given dominant size class regardless of the subdominant size class. For the Lower American River, substrates from 90% gravel (0.1" - 2.5") / 10% cobble (2.5" - 10") to 90% cobble/10% boulder (10" - 13') were optimal; this would correspond to CDWR's substrate two-digit codes of 34 (dominant small gravel, subdominant large gravel/small cobble) to 56 (dominant cobble, subdominant boulder) having a suitability of 1.0. For the Feather and Yuba Rivers, substrate criteria were transformed by averaging the suitabilities of several size classes used in the Feather or Yuba River criteria that were included in one Sacramento River size class. The resulting weighted useable area curves calculated from the five sets of HSI criteria are shown in Figure 4. Most notable is that the Sacramento preference criteria were the only criteria to result in a monotonically decreasing function of weighted useable area versus flow; weighted useable area versus flow peaked at 3,500 cfs for the Lower American River criteria and peaked at 4,500 cfs for the Sacramento River use and Feather and Yuba River criteria. This result is probably due to the higher suitable velocities for these four sets of criteria, versus the Sacramento River preference criteria (Figure 1). The other main difference between the different weighted useable area curves is a vertical shift in the curves, probably due to differences in substrate criteria, particularly the lack of consideration of subdominant size classes for the Feather, Yuba and American River criteria.

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[1] The same code was used for both the dominant and subdominant size class in a two-digit number, with the first digit being the dominant size class and the second digit the subdominant size class. For example, a substrate composed of mostly large gravel with some small gravel would have a substrate number of 43.

Figure 1

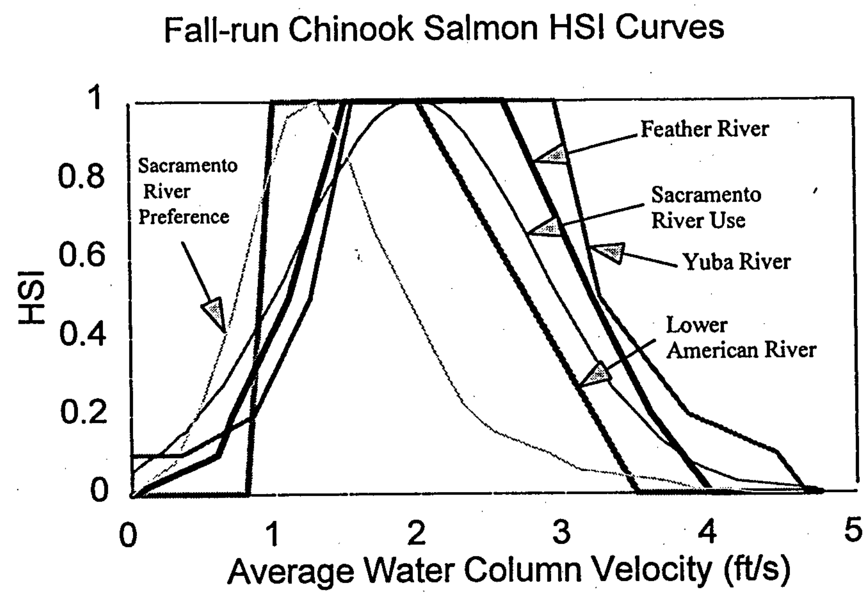


Figure 2

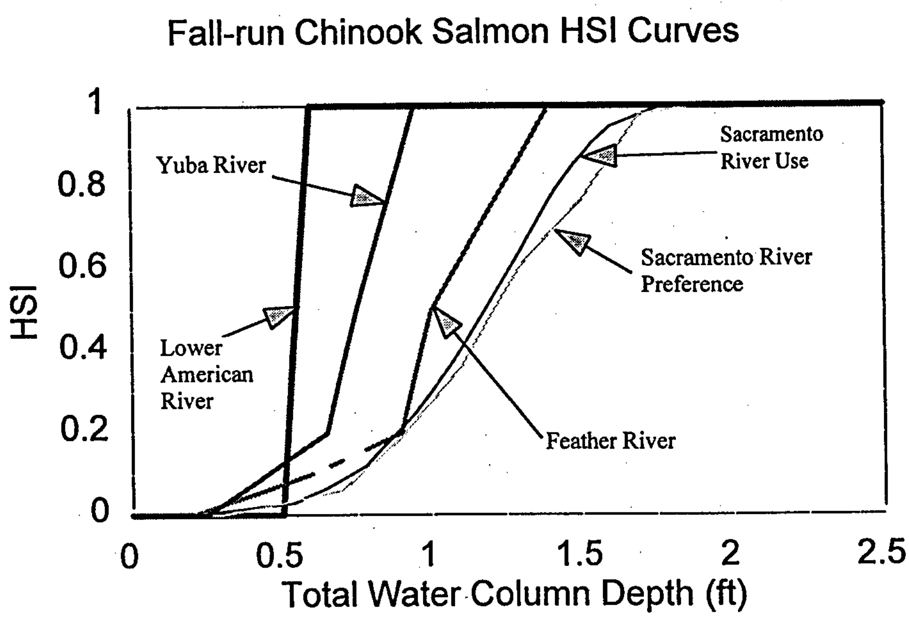


Figure 3

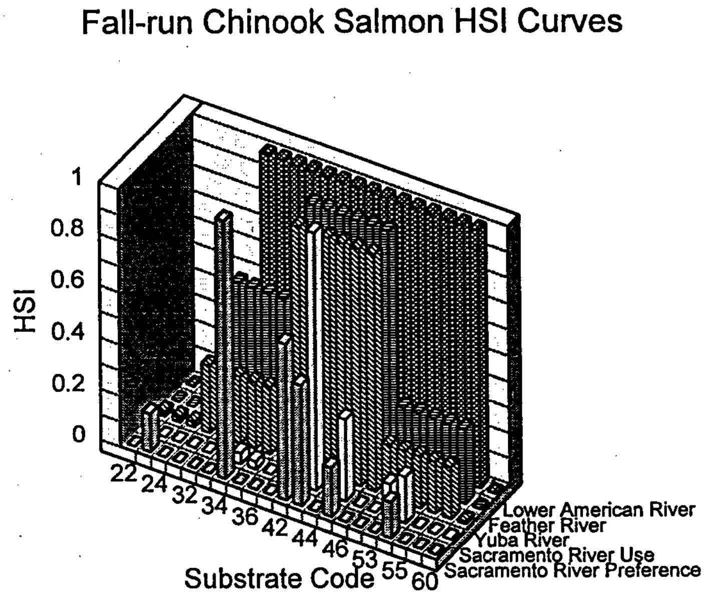
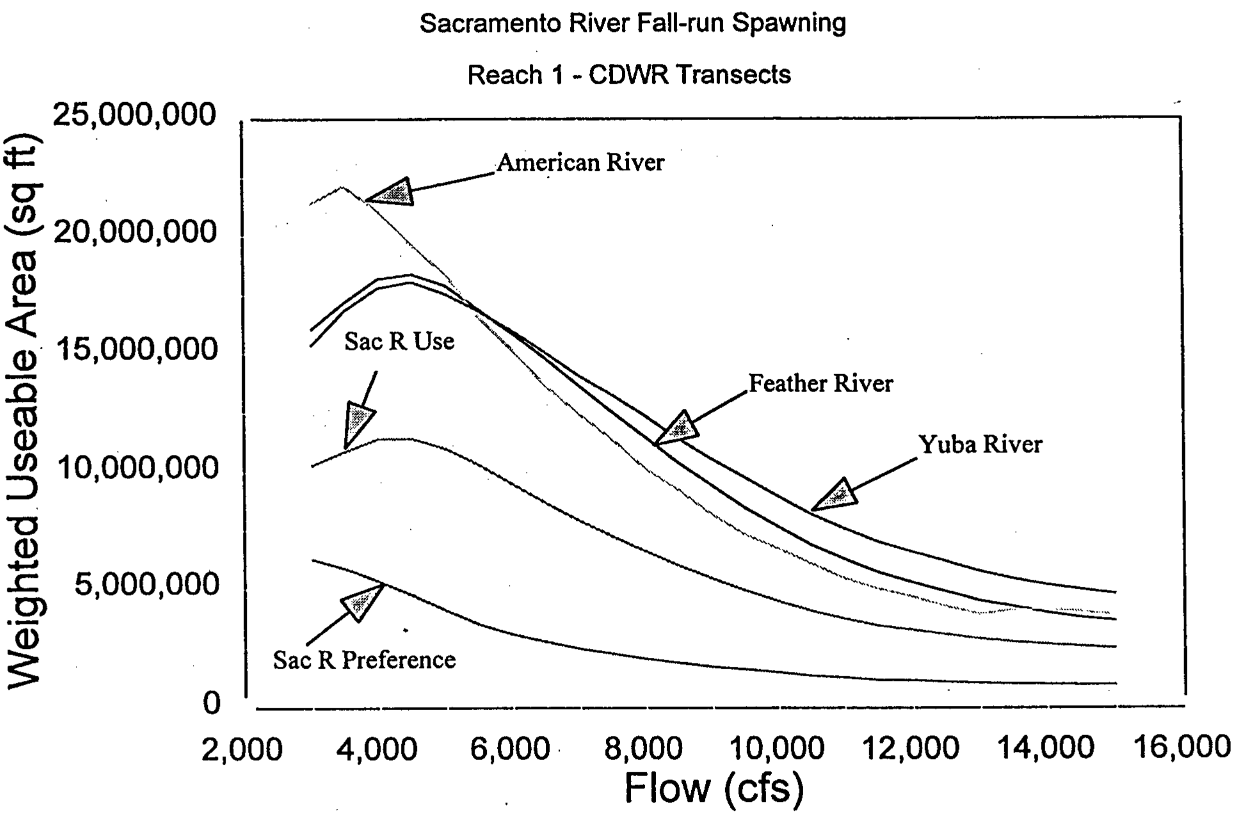


Figure 4



To derive habitat use criteria for fry rearing, all CDFG Sacramento River data for juvenile fall-run salmon less than 65 mm for which there were measurements of all three habitat parameters (depth, velocity and cover) were pooled. Frequency distributions for depth and velocity were developed and input into the CURVE utility in PHABSIM. HSI curves were then derived with CURVE using fourth order exponential curve fits. Cover HSI criteria were calculated by dividing the frequency of habitat use for each cover category by the cover category with the highest frequency of habitat use. The resulting HSI fry rearing curves and criteria are shown in Figure 4 and 5 and Table 2. In this case, the use data suggests that optimal velocities are lower than the preference data, which would likely result in a peak weighted usable area at a lower flow for the use, versus the preference, criteria. In addition, the use criteria for cover does not make biological sense, since juvenile fish would be expected to use cover preferentially to reduce the threat of predation. It is likely that the use data show no cover to be optimal because there was a much greater effort spent collecting use data in areas with no cover. Another issue that arises from the fry rearing criteria is whether suitability is optimal for deep waters; from biological considerations, it would be expected that suitability of deep waters would not be optimal due to the increased risk of predation by piscine predators in deep waters. I also derived fall-run chinook salmon fry rearing use depth HSI curves, conditional on the presence or absence of cover (Figure 7). As would be expected from biological considerations, fry are found in deeper waters in the presence of cover; in the absence of cover, juvenile fish shift to shallower waters to reduce their risk of predation by piscine predators.

Frequently, juvenile HSI curves which show low velocities and depths to be optimal result in the greatest weighted usable area for juvenile rearing at the lowest flows, while production of salmon tends to be greatest in years with high flows. Three approaches that could reconcile these observations would be: 1) to use an adjacent velocity criteria for juvenile rearing, based on the observation that juveniles tend to be found in areas with low velocity to conserve energy, but are found near areas with high velocities, where food availability is high; 2) to use a modified habitat mapping approach, in which transects are weighted by the number of juveniles in different mesohabitat types (calculated as the product of mesohabitat area times the juvenile density in a given mesohabitat type); and 3) to develop aquatic macroinvertebrate criteria, since food production, rather than habitat area, may be limiting juvenile survival.

The suitability of deep waters for spawning is another issue, since the frequency distribution of spawning depth data shows a decrease in spawning use for depths greater than 2.2 feet. This phenomena could be due to a lack of availability of suitable velocities and substrates in deeper waters. To test this hypothesis, I used the CDWR Sacramento Reach 1 data decks to calculate the percentage of area with useable velocity and substrate (using the Sacramento River use HSI criteria) for depths greater than 2.6' (the depth at which the original HSI use curve for depth that I derived reached a suitability of 0.5). At a flow of 5,500 cfs (the average flow at which CDFG collected fall-run spawning habitat use data, 18% of water deeper than 2.6' had suitable velocities and substrates, while 20% of all waters had suitable velocities and substrates, suggesting that a decrease in spawning use for deep waters is not due to a decrease in useable velocity or substrate.

Figure 5

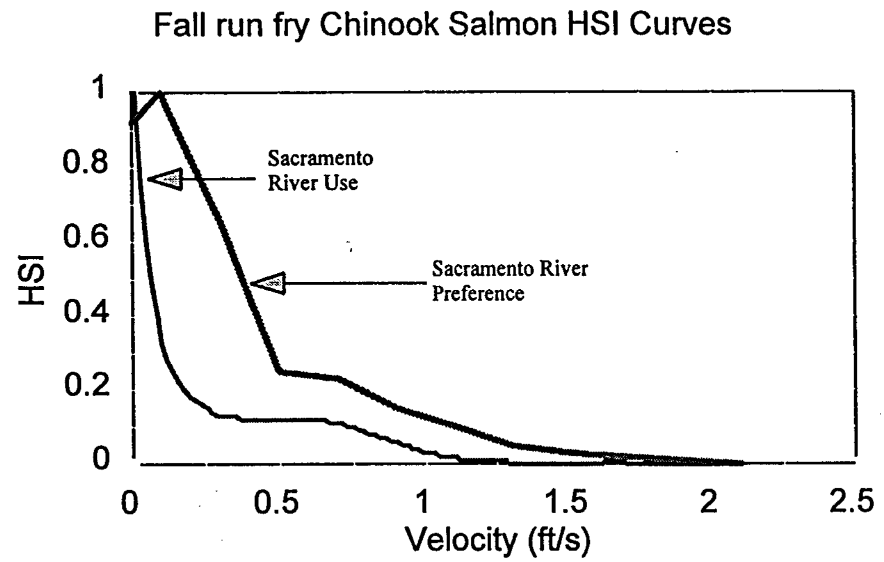


Figure 6

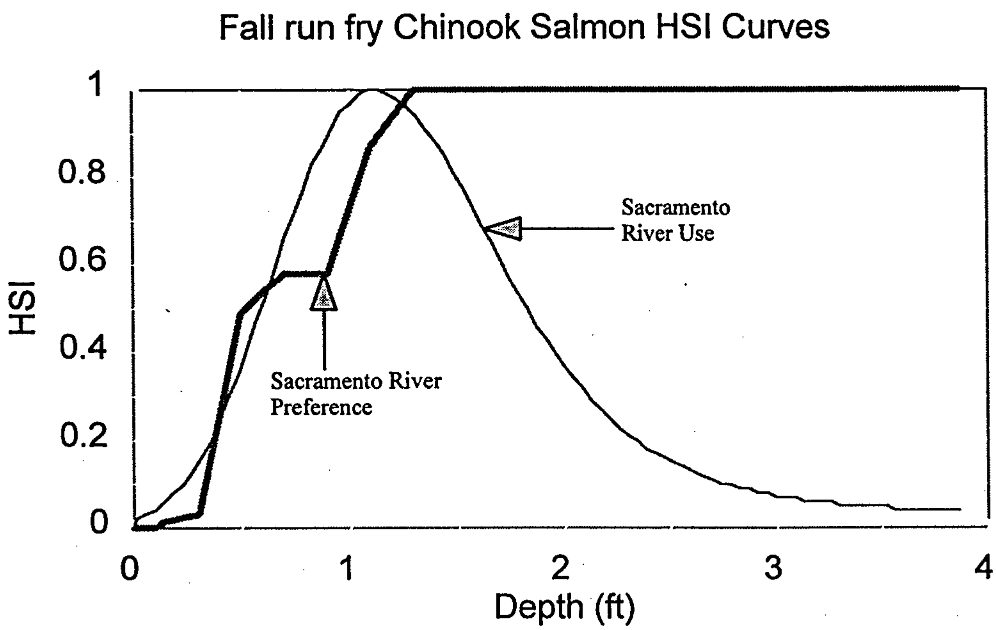


Figure 7

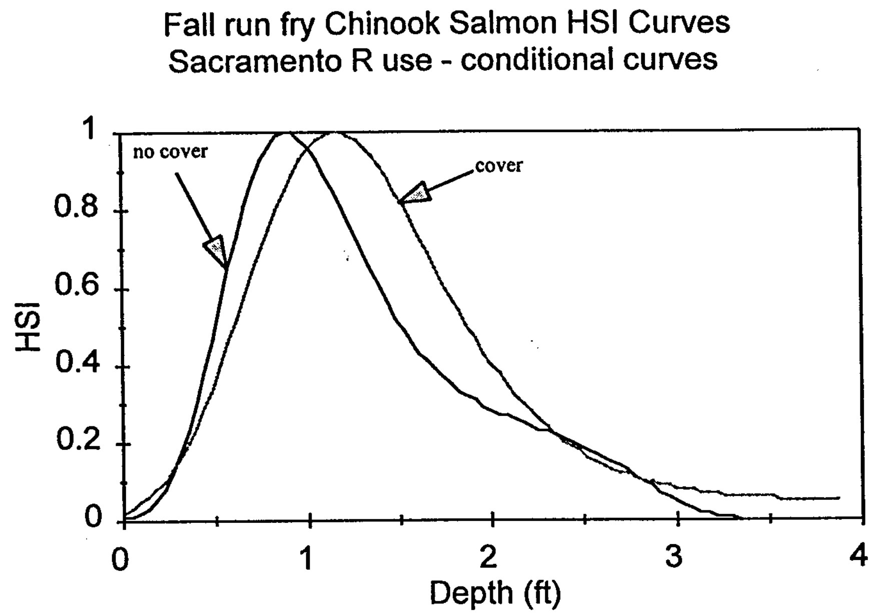


Table 2

Fall-run chinook salmon Sacramento River fry rearing cover criteria

Cover category	Use criteria	Preference criteria
No cover	1	0
In-stream cover	0.95	0.11
Overhead cover	0.23	0.42
In-stream and overhead cover	0.82	1
Riprapped banks	0.28	0

Alternatively, the lower frequency of redds in deeper waters could have been due to less effort spent in deeper waters. One way to evaluate the suitability of deeper waters would be to conduct a transferability test (Thomas and Bovee 1993) with two sets of criteria: one with decreasing suitability at greater depths, and the other with optimal suitability for deep waters. This technique could also indicate whether other variables, such as distance from shore or local bed slope, should also be included in the criteria. Observations of redds in the Sacramento River have noted a phenomena of lateral redds, nearshore, and that redds tend to be in the upper third of riffles. Salmon may prefer to build their redds in the upper third of riffles, where the bed slopes up going downstream, because these conditions increase the penetration of water into gravel.

Another important issue that needs to be resolved before data for spawning HSI criteria are collected is the substrate classification scheme to be used (which size classes to use and whether to use a subdominant size class and/or percent fines). Percent fines were not used for CDFG's Sacramento River criteria because it was assumed that fines would be washed out of the substrate when the salmon constructed their redds.

CDFG attempted to develop a total of 144 sets of criteria: one for each of three races (fall, late-fall and winter-run), for each of four reaches, for each of four flow ranges and for spawning, fry rearing and large juvenile salmon rearing (3 x 4 x 4 x 3). When developing HSI criteria based on microhabitat use, data should be collected at intermediate flows, so that a full range of microhabitats are available (Bovee 1995). In addition, it is generally assumed that microhabitat use is a genetic characteristic, and thus, while it might be different for different races[2], it should not differ for different reaches or flows, assuming that a full range of microhabitats are available. Thus, there is no reason to develop different criteria sets for different reaches or flows.

A logistical problem in collecting microhabitat data on spawning is determining what the water depth and velocity was when the redd was constructed. Typically, measurements have been made of existing redds which are identified as new due to a lack of periphyton growth on the redds. However, redds, especially in deeper waters, can remain free of periphyton growth for up to 3-4 months after they are constructed (Frank Fisher, CDFG, personal communication). Since the flow when microhabitat measurements of the redd are made is probably different than the flow when the redd was constructed, the depth and velocity measured will be different than when the redd was constructed. Since it is probably impractical to only make measurements of redds under construction, a better approach to address this problem would be to map redds at weekly intervals, during periods when flows are not varying significantly, to identify which redds were constructed during each week. Data would then be collected on these redds for HSI criteria, since the depth and velocity measured for newly constructed redds would be close to that when the redds were constructed. The redds could either be mapped with photographs taken from a boat or during aerial redd surveys, or by divers.

Conclusions

1) Transferability tests (Thomas and Bovee 1993) should be conducted as a first step in developing spawning HSI criteria to determine suitability for deep waters and which additional variables should be included in HSI criteria.

[2] Microhabitat use also is affected by water temperature, which could result in different criteria for different races, since differences in seasonal timing of different races would result in different water temperatures for the same life stage of different races.

2) Chinook salmon spawning HSI criteria should be developed based on habitat use data, with availability addressed by spending an equal effort collecting data in different mesohabitat types. Since different mesohabitat types have different ranges of depths and velocities, this approach should be able to address whether spawning suitability is less than optimal for deep waters.

3) Chinook salmon juvenile rearing HSI criteria should be developed based on habitat use data, with availability addressed by spending an equal effort collecting data in different mesohabitat types and cover types. Data on adjacent velocities should be collected as part of the habitat use data. The size of each juvenile should be recorded. The data should be evaluated to determine if depth criteria conditional on cover should be used.

4) A transferability test should be conducted to see if existing aquatic macroinvertebrate HSI criteria can be used on the Sacramento River.

5) A total of 9 sets of chinook salmon criteria should be developed: spawning, fry rearing, and large juvenile rearing for fall, late-fall and winter-run races. Fall-run criteria should be used for spring-run. The size used to separate fry from large juveniles should be selected which minimizes the variability of microhabitat values within each of the two size classes.

6) Spawning data should only be collected on newly (within a week) constructed redds during periods when river flows are not changing dramatically.

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